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Performance aspects of Lévis substation DC de-icing project

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Abstract— **Hydro-Québec TransÉnergie will install a DC converter at Levis substation to de-ice line conductors using Joule effect. This paper describes different technical aspects that have been considered in the planning process to insure that de-icing installation will perform as expected in presence of a severe ice storm. The main design parameters of the installation, the special cycling operation of the installation and the control system will be discussed in the paper.**

I. NOMENCLATURE

DC converter, Static Var Compensator, De-icing method, OPGW (**OP**tic fibre **G**round **W**ire).

II. INTRODUCTION

In 1998, a major ice storm occurred over five-day period along the St-Lawrence River near Montréal. During this event, the ice reached a thickness of up to 75mm. Towers collapsed due to the excess of ice weight on the line conductors, causing the loss of electrical supply to many customers. TransÉnergie has developed different strategies to allow substantial reduction of customer service interruptions resulting from extremely severe icing conditions [1], [2]. One of them is to implement a DC de-icing facility with a combination of mechanical reinforcement of towers to maintain in service a minimum of the main frame at 735 kV. The first world de-icing scheme using DC technology will be installed at Levis Substations.

This paper presents the considerations having influenced the project concept such as conductor thermal capacity, disconnect switch requirements, particular de-icing operating sequences and the operating control features.

III. DC TECHNOLOGY FOR DE-ICING LINES

A. Overview

Reinforcement of the 735 kV lines to cope with more severe climatic conditions (ice accumulation and wind speed) has been analyzed but soon abandoned due to its excessive investment. Mechanical de-icing methods, which can be performed only on short line sections at a time, have not been considered for long lines with bundled conductors. AC system methods such as low or full short-circuit methods [3] allowing a complete line de-icing in a single step have also been abandoned because of the voltage and power magnitudes required. For instance, to de-ice a 250 km section of 735 kV line with a bundle of four conductors the voltage and power of the source should respectively be around 1000 kV and 12 000 MVA which are beyond the system capability.

Remembering that de-icing by Joule effect deals only with the RI^2 losses, a DC source takes advantage of the high X/R ratio of the line. The power source required decreases by the same ratio since the voltage source corresponding to $I^*(R+j\omega L)$ is only proportional to R in direct current. In comparison with the previous 12 000 MVA AC source, de-icing the same 735 kV line (typical X/R of 30) would need a DC source of only 400 MW to perform de-icing on three phases. Such a converter size is technically feasible and does not cause any adverse impact on the system especially if the power is ramped up (intrinsic to DC converters).

B. De-icing currents

Conductor current shall be high enough to melt the ice accumulated without exceeding its thermal limit. The thermal limit is defined at 95°C conductor temperature assuming an ambient temperature of 0°C and wind velocity of 2,2 km/h. Table 1 shows the maximum current for commonly used conductors on TransÉnergie system. For a typical 735 kV line with a bundle of four 1354 MCM conductors per phase, the de-icing current is 7200 A per phase. A bundle of two 666 MCM conductors as used on 315 kV lines would need 2300 A per phase.

TABLE 1
CONDUCTOR MAXIMUM DE-ICING CURRENT

Conductor	Maximum current
1354 MCM	1800 A
1028 MCM	1600 A
666 MCM	1150 A

Considering the current limits mentioned here above, TransÉnergie has started extensive laboratory tests to establish the correlation between ice melting time, ambient conditions and radial ice thickness deposited on the conductors. Two different campaigns have been realized at IREQ laboratory facilities and provided sufficient data's to establish relation between melting time, injected currents and ambient de-icing conditions [4]. A new software program has been developed to provide the minimum de-icing current and the corresponding melting time under various ambient conditions. For the current level mentioned in table 1, results indicate that 30 minutes of current injection is required to de-ice 12 mm of radial ice on a conductor if ambient temperature is at -10 °C and transversal wind velocity is 10 km/h. Results of the tests performed on a full scale section of a 735 kV line (90 m) were very close to those provided by the software. Differences came essentially from the weather conditions that were continuously changing during field tests (ambient temperature, solar radiation and wind velocity).

C. Description of the de-icing concept

The DC converter at Lévis substation (see Fig. 1) will be used to de-ice 5 lines ; four 735 kV and one 315 kV double circuit line. The DC current capability is 7200 A. This current corresponds to the highest de-icing current required among the five lines.

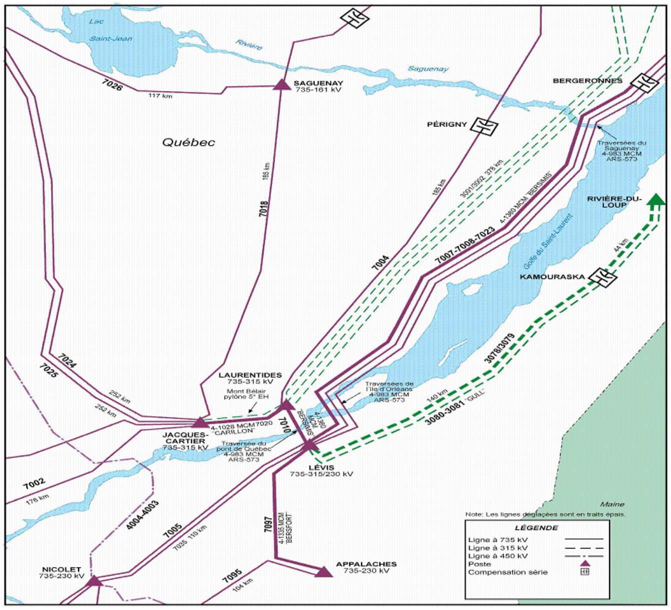

FIG. 1 Map of levis substation and incoming lines

The DC de-icing requires the formation of a closed loop using line conductors as shown in figure 2 or a loop of two transmission lines connected in series (round trip to the next substation). The ground return path cannot be used because of the adverse impact of high magnitude DC current (up to 7200 A) on the transmission system. Transformer saturation and voltage distortions are some of the consequences. Thus a metallic return is mandatory. The three phases de-icing cannot be performed in a single sequence on 735 kV lines even using another 735 kV as a metallic return because of the very high de-icing current required (3 x 7200 A). Two or more consecutive steps are necessary.

Knowing also that phase arrangements (series and parallel phase conductor connections) have an impact on the DC converter rating, optimization of de-icing configurations has been performed. For the longest 735 kV Lévis-Bergeronnes line, one phase (the one being de-iced) is connected in series with the two others in parallel (the metallic return path) in order to reduce the DC source size. Same operation will be performed two more times by switching phases in order to perform de-icing on the two other phases. Proceeding this way a 25% reduction on the converter rating resulted.

One of the arrangements is presented in figure 2. Two phases are connected in series to form a loop and the DC pole terminals are connected to this loop. The two phases are de-iced simultaneously in the same sequence. In the second sequence the third phase is connected in series with one of the two "already de-iced" phases.

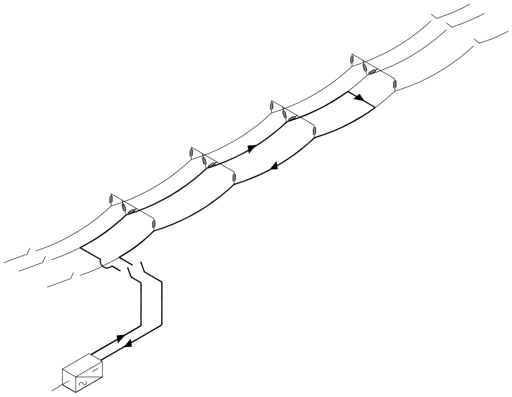

Fig. 2 One of the two step sequences required to de-ice line phase conductors

A third sequence is necessary for lines equipped with an OPGW (**OP**tical fibre **G**round **W**ire). This ground wire is connected in series with one of the phase conductor as the return path. OPGW are mainly used for line protections as well as for special protection systems (SPS). Considered as part of strategic equipments, the OPGW shall remain unaffected under very severe ice conditions. Unfortunately, the existing OPGW are not mechanically designed to withstand a severe ice storm as in 1998. For this reason, the DC source has also been chosen to de-ice the OPGW. In this case the OPGW shall be electrically insulated from the tower. This will be discussed in chapter G.

Table 2 shows the transmission lines concerned by the project. Number of sequences required is also shown. For the first three lines, two sequences are required to de-ice the phase conductors and a third one for the OPGW. The Lévis-Bergeronnes line has no OPGW so the three sequences are dedicated to the phase conductors as mentioned above. For the 315 kV line connecting Lévis and Rivière-du-Loup substations it is possible to perform three phase de-icing in the same sequence because the required current (6 900 A) is lower than the DC converter nominal current. To achieve this, the three phases of each circuit shall be connected in parallel and the two circuits connected in series to the converter terminals.

Because of the different line lengths and conductor sizes including the OPGW, the DC installation must have a wide range of voltage and current operating capabilities. For instance the OPGW requires only 600 A while the 735 kV lines require 7,200A per phase. A special requirement of continuous current operating capability at 600 A have been asked since it is less than the usual practice in the industry.

TABLE 2
DE-ICED LINE CHARACTERISTICS

Substations From / to	Line voltage (kV)	Length (km)	Size Conductors MCM	Number of sequences
Lévis / Appalaches	735 (S *)	78	4 * 1354	3
Jac.-Car/ Laurentides	735 (S *)	34	4 * 1028	3
Lévis /Laurentides	735 (S *)	27	4 * 1360	3
Lévis / Bergeronnes	735 (S)	242	4 * 1360	3
Lévis /Riv.-du-Loup	315 (D)	183	2 * 666	1

S = Single circuit line D = Double circuit line
(*) line equipped with an OPGW

Once established the connection principle, the next step is to transfer the transmission line(s) from the AC to the DC system using the AC line breakers and de-icing disconnect switches. These disconnect switches are used to create the conductor loop and to connect the DC source to conductors. The existing line disconnects may be opened if they are mechanically designed to operate under severe ice conditions otherwise they will remain closed.

D. Line modifications

Line design criteria's have evolved through the years. Also, it should be noted that line exposure to ice storm depends on its geographical location. From this, appropriate modifications have been implemented for all exposed lines. Modifications involve mainly the replacement of steel ground wires, the reinforcement of the structural ground wire attachment to avoid sliding, the reinforcement of some tower steel members, the integration of new anti-cascade towers and OPGW electrical insulation needed for de-icing.

E. Levis substation modifications

To connect DC converter to AC lines, a new DC busbar is required (one per pole). These busbars connect lines to the converter via special 735 kV disconnect switches. Also, the location of the DC installation in the substation was a very important issue because of constraints on the audible noise due to the proximity of residences nearby. Studies revealed that the most appropriate location was right in the middle of the substation.

F. DC converter design requirements

Using a DC converter only for de-icing purposes is not only difficult to justify economically but its availability is also problematic since the expected utilization is about once per 50 years. Based on this, converters should preferably operate on a permanent basis to insure equipments are available when needed. TransÉnergie has then adopted the static var compensator as the other operating mode of the DC installation. The static var compensator will improve the local voltage regulation on a day to day basis and at the same time maintain in operation most of the DC converter equipments including protections and controls. The transfer time allowed from one operating mode to the other mode has been established to one hour (see sub-section I). The main parameters in both operating modes are :

	De-icer mode	**SVC mode**
Nominal power	250 MW(0°C)	+250Mvar,-125 Mvar(30°C)
Dc current	7200 A	loss evaluation (± 75 Mvar)
DC voltage	± 17,4 kV	
Temporary overload	300 MW (1,5 Hr) At ± 20,8 kV	
Transfer time	1 hour	

Temporary overload of 300 MW has also been requested to cover an additional de-icing need. Indeed, it has been decided to de-ice 100% of the 315 kV line length between Lévis and Rivière-du-Loup substations instead of 80% as initially planned in the preliminary studies. With this additional capability, the 315 kV line section could be de-iced completely with a minimum investment in the DC installation.

G. Dielectric withstand under icing conditions

Reduction of the dielectric withstand under icing conditions is also a major issue. To make sure equipment integrity will not be affected during icing conditions, a 350 kV BIL has been specified for the DC apparatus. This insulation level, same as for 69 kV equipments, is standardized at TransÉnergie thus avoiding the need to certify a new class of equipments. The extra cost resulting is negligible. On the other hand, equipment whose operation could be jeopardized during an ice storm will be protected by a shelter (ex.: power transformer cooling fans, etc.).

On the other hand no modification is necessary on line insulator strings due to the low voltage applied during de-icing process (20 kV maximum) compared to the insulation level of 315 and 735 kV transmission lines. The only concern is the line re-energization following a de-icing operation while insulator strings are still ice covered. At 735 kV, the risk of having a flashover is higher due to a lower insulation margin in comparison with the 315 kV. However, field experience on the 735 kV network showed an average of only one flashover per year due to the ice or snow accumulated and subsequent line re-energization has always been successful.

Optical fibre ground wires have to be insulated from the tower. Insulator strings are specified with a margin covering the breakdown of one unit in any string. In addition, insulator strings will have a horn gap in parallel protecting the insulator against lightning strike flashovers. The gap is designed in such a way to flashover below the insulator withstand voltage and also to interrupt the 60 Hz induced current.

H. Operating considerations- Disconnect switches- maneuverability during ice storm

At the very beginning of the studies, TransÉnergie taught that development of a new disconnect switch would be necessary for the 735 kV application because of the high current magnitude required current (7200 A) and the ability to maneuver with an ice thickness accumulation of more than 50 mm which is much higher than standard value considered in the industry (20 mm max.). Preliminary schemes have been proposed and technical evaluation showed that this approach could require a major effort in R&D development. Such a development could impact the commissioning date of 2006 so TransÉnergie decided to reorient the solution and looked to adapt existing technologies currently used on the system. With the collaboration of its main supplier, the existing 735 kV disconnect switches (limited to 4000 A), for which minor modifications on electric parts are implemented, appeared to be adequate for this application. Also, current requirement has been redefined on a temporary basis (1,5 hour) rather than permanent basis. Tests performed on the modified disconnect switches showed maximum hot spot temperature of 110 °C after a 1,5 hour application at 7200 A. This “higher than usual value” as been accepted considering the low probability of utilization in de-icing mode. The temperature of other parts of the disconnect switch were less than 110°C, but still high enough to insure a rapid ice melting on the electrical parts of the disconnect switch. Despite this benefic behavior, TransÉnergie has requested that disconnect switches should have a minimum capability to operate with a 50 mm ice thickness radial deposit.

I. De-icing cycle at Levis substation

Ice monitoring equipments will be installed on transmission lines to be de-iced. Information is transmitted to the operating center and will be used to initiate the de-icing operation.

During de-icing process, many operation actions are required on the AC system before, during and after the line is de-iced. In sequence, it is required to :

- isolate the line
- protect AC and DC system against inappropriate closure of line breakers
- configure correctly the de-iced switches
- operate the de-icing converter
- transfer the line back to AC system.

All these actions require time for the execution. During ice storm, ice continues to accumulate on the lines at the rate of about 2 mm/hour and with a maximum of about 25 mm/day. TransÉnergie has evaluated if operating and de-icing sequences can be realized inside a reasonable time frame to insure that ice accumulation will not exceed mechanical line design. Figure 3 shows the required time for each of the 5 lines considering switching and de-iced durations based on TransÉnergie operating practices and a fixed 1 hour for de-icing time.

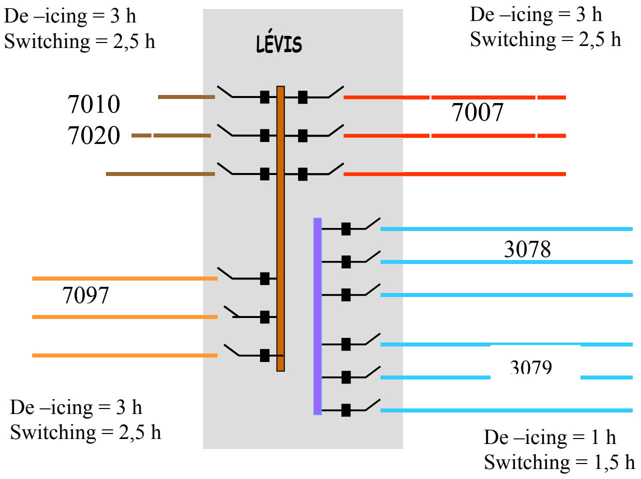

Fig. 3 Time required for de-icing each line

To realize the complete cycle, the study shows that the sequence requires about 19 hours. The scheme has been verified with a complete simulation of the event of January 98 (5 days, 75 mm radial ice) applied at Lévis substation. The study results show that ice accumulation on line conductors should be well under the 25 mm ice thickness design limit of the lines. Figure 4 shows the maximum ice accumulation on different lines assuming the event of January 98 at Lévis Substation.

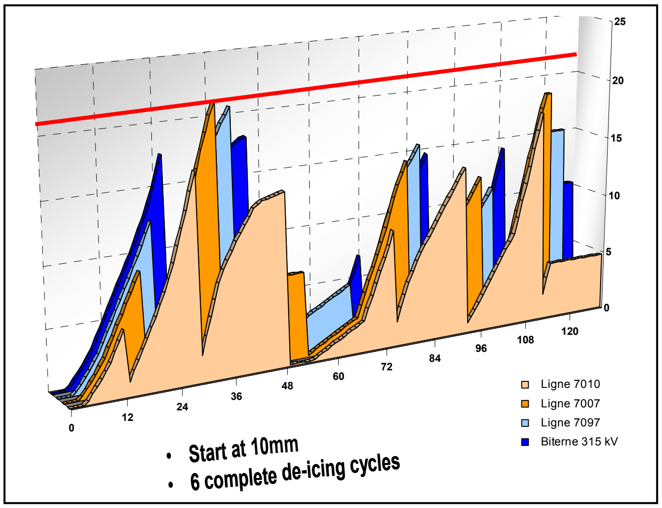

Fig. 4 Ice accumulation on different lines assuming the 5 days ice storm of January 98

It is assumed in this case that de-icing operation has started with a minimum ice accumulation of 10 mm.

J. Operating system with a De-icing control unit

The DCU (De-icing Control unit) fulfills a primordial role in the coordination and the supervision of all the actions required to perform de-icing on the 5 lines. To insure high reliability of the de-icing sequences and provide network security, the DCU control should be able to do different tasks, such as :

- validate the isolation of the line from AC network;
- modify some AC protections to cover special events ;
- select and control de-icing disconnect switches at Lévis substation and at the remote line end ;
- control all the parameters of the de-icing converter and transfer the line back to AC system.

All data, operating status and system controls will be concentrated in the DCU controller. Also, the DCU shall be operated either at the regional dispatch center or at the Lévis main control building. Over 276 operations will be performed by the dedicated DCU operator. To facilitate his task, all the sequences will be pre-programmed and showed directly step by step on the operator display screen. At least once a year, the staff will practice all the sequences in order to check the integrity of components, control and protections and also to get familiar with the de-icer operation. For this purpose, a “test” mode have been added to the two main operating modes of the installation (De-icing and SVC).

The diagram below summarizes the algorithm that will be implemented in the DCU to insure security, control and switching actions during the de-icing process.

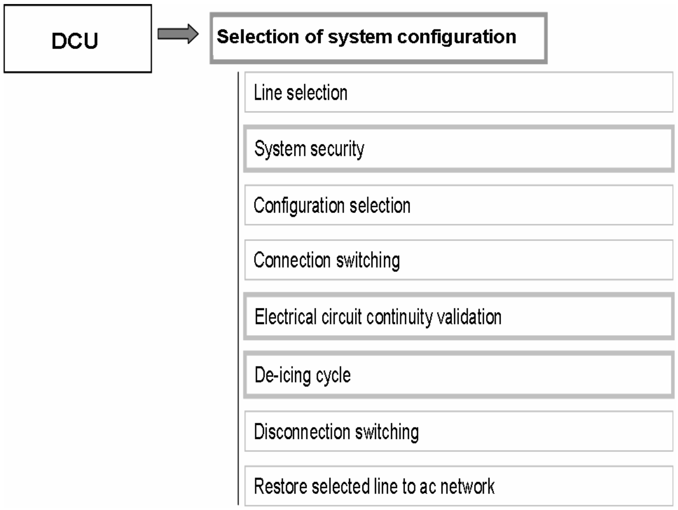

Fig. 5 Actions performed by the De-icing Control Unit

Having realized the network security and the electrical connections, the next sequence is validating the integrity of the DC circuit. At minimum DC converter current, the electrical parameters of the line will be measured and compared with internal reference data. Following DCU validation, DC current will be ramped up at the appropriate de-icing current considering ambient temperature conditions. After a delay of 1 hour, the DC current will ramp down to zero and temporary blocking will be applied to DC converter. Figure 6 summarizes the DC current profile during a de-icing sequence.

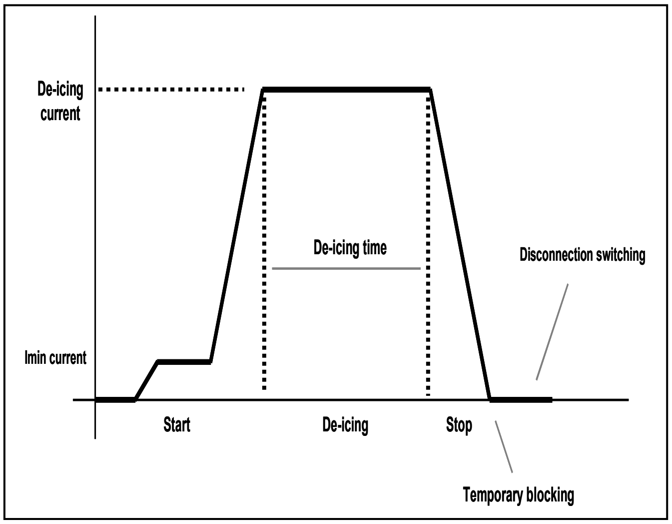

Fig. 6 DC curent injected during normal de-icing sequence

Different control architectures have been examined to insure simple concept in the integration to the actual system. It reveals that DCU should be separated from control functions dedicated to the de-icer converter. Figure 7 shows the actual control architecture planned for controlling the de-icing system.

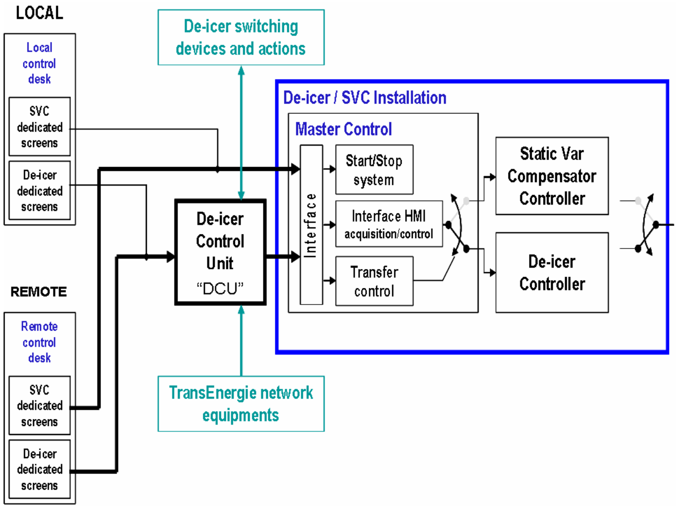

Fig. 7 De-icing control architecture of the system

IV. CONCLUSION

In order to avoid tower collapsing due to severe ice storms, TransÉnergie has developed a new defense plan. Strategic transmission lines have been identified to face exceptionally severe ice storms. A combination of tower reinforcement and de-icing methods has been identified has the best solution to achieve the goal.

For 735 kV lines, the DC technology is the most practical method to de-ice line conductors. The Québec area, and more precisely Lévis substation, has been identified has a strategic location to install the first DC de-icing system. Five incoming lines will be de-iced including their optical fibre ground wire.

The DC installation rated at 250 MW and operating at +/− 17,4 kV will be in operation by 2006. It will also be used as a static var compensator on a day to day basis to improve the local voltage regulation and to insure its availability for de-icing purpose.

In de-icing mode, the DC installation will provide up to the 7200 amperes required to melt ice on the four conductor bundles. Development and testing of an appropriate disconnect switch was required to make sure it can operate safely considering the high current level and ice accumulation. A de-icing control unit (DCU) is an essential device to supervise the numerous actions required to perform a complete de-icing cycle of the five strategic lines and to secure a safe operation between the AC system and the DC installation.

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