Demonstration of the Feasibility of a New Mechanical Method of Cable De-Icing

Jean-Louis Laforte*, Marc-André Allaire **, Caroline Laforte*

*Université du Québec à Chicoutimi, Chicoutimi, QC, Canada, G7H 2B1
***Déglaçage Industriel DGI Inc., Chicoutimi, QC, G7G 2V7

Abstract – **During the last two years, progress has been made in the field of de-icing technology as a result of the development of a new very simple technique in which an overhead cable is de-iced by twisting. With this new mechanical method, the iced cable is rotated in the elastic domain of deformation at one end, while fixed at the other extremity. The ice bond is broken at the ice/cable interface by the elastic energy accumulated during twisting. The objective of this paper is to describe the principle of the new method along with three of the outdoors tests demonstrating its effectiveness. Two tests were conducted during the winter of 2003 on a 200 m-long, 11 mm diameter ground wire covered by ice deposits of 25-30 mm Radial Equivalent (Re) thickness. Ice was completely removed by twisting the iced cable two sequences of ten rotations at –8 and –12 °C. The third test was performed during the winter of 2004, where a prototype of a hand-twisting device was used for de-icing a 15 m-long, 11 mm diameter iced ground cable. In all these tests, the method was found effective in removing ice deposits as thin as 1 mm thick. The main advantages of the twisting method are threefold. It does not require any sheathing. The mechanical energy needed for twisting is very low, thus de-icing a span-long cable can be performed with a twisting device in 2-3 minutes, as compared to 2 hours required under ideal conditions by a person using a hitting device mounted on a lift. Last, but not least, the method is environmentally safe. Moreover, the new method can be easily motorised and automated so several spans of cables can be de-iced simultaneously.**

I. INTRODUCTION

In the cold and temperate regions of North America, Europe and Asia, ice and snow build-up can cause very serious problems to overhead power line conductors. Depending on conditions, ice accumulation can exert excessive static loads on overhead cables and their structures. Under windy conditions, when ice forms aerodynamically unstable shapes on the conductor, it may also apply severe dynamic loads. Since building power lines to withstand the most severe ice/wind load conditions is neither practical nor economical, one alternative is to de-ice the lines during icing storms. Unfortunately, although there are many different de-icing techniques reported in the literature (**Ref. 1**), none of the methods investigated so far have proved to be effective in solving all power line icing problems. Thus the study of de-icing methods has always remained a subject of major interest for utilities. This paper aims to describe the exploratory research work conducted during the winters of 2003 and 2004 for demonstrating the effectiveness of a new, very simple de-icing technique consisting of twisting the cables. This very simple method can ultimately be further developed and adapted for power line anti-icing and de-icing interventions during and following ice storms; first on overhead cables with low rigidity such as ground cables, and later on more rigid overhead cables like conductors. Following a short review of the existing de-icing techniques, especially mechanical ones, this paper presents the results of three de-icing tests in which the effectiveness of the new technology was successfully demonstrated on non-energized cables.

II. REVIEW OF DE-ICING TECHNIQUES

More than forty de-icing techniques, capable of removing ice and ensuring anti-icing protection, can be found in the literature (**Ref. 1**). They are classified into four main categories. The first two classes comprise thermal and mechanical methods, based on melting and breaking ice respectively. The last two categories include passive and miscellaneous techniques. The former is made up of special coatings that reduce ice-adherence or specially designed devices favouring ice shedding based on natural energy, such as wind, solar radiation, or gravity. The latter contains all methods that cannot be included in the first three. This short review will focus only on thermal and mechanical methods (Table 1).

A. Thermal methods

Most of the thermal methods were specifically developed for de-icing power line cables and conductors to be able to supply the high power required. They are mainly based on the Joule effect, requiering the circulation of high current in the cable itself. Other methods include using an external envelope heated by means of resistive wires, or those made of ferromagnetic alloys, in which eddy currents are induced in AC. While efficient, thermal methods consume relatively large amounts of power. Anti-icing and de-icing require 1.0 and 1.3 kW/m^2 respectively. For a 100 km-long line with three bundles of four conductors 35 mm in diamter, the total length to be de-iced is 1,200,000 m, with an ice-exposed area averaging 0.11m^2/m. The power consumed by Joule-heating can be estimated to be 1,200,000 m x 0.11m^2/m x 1 kW/m^2 = 132,000 kW = 132 MW. The remaining external heat source thermal methods were specifically developed for aeronautics and railroads, and are therefore difficult to apply to ovehead cables. They are: hot gases, for de-icing wing leading edges and other critical parts of aircraft in flight; freezing point depressant fluids, applied to aircraft to de-ice and ensure anti-icing protection before take-off, and electromagnetic wave beams, such as microwaves, lasers, and infrared beams.

B. Mechanical methods

On the basis of laboratory tests, the mechanical break-up of a given mass of ice requires around 100,000 to 2,000,000 times less energy than its fusion. However, in practice, the energy efficiency of the various mechanical techniques ranges between 3% and 4%. Altogether, mechanical processes require about 200 times less energy than thermal ones. They comprise methods in which the ice is broken by means of a tool brought into contact with the ice (scrapers, rollers, cutters, sticks, etc.) (**Ref. 2**) or operated at distance (particle jets, projectiles, shock waves, etc.). They also include the less common techniques, in which shock is transmitted through the iced components, which then shed the ice coating. Shock can be produced in one of four ways: by means of an explosive device (**Ref 3**); a mid-span vibrating system powered from own line current; an inflatable pneumatic envelope, or an electro-expulsive sheathing (**Ref. 4**). The latter technique, also called the EIDI method, has already been successfully used in aircraft de-icing applications.

TABLE 1
SUMMARY OF DE-ICING METHODS

Type	Short description
Passive	Incidental radiations, gravity, wind, ice phobic coatings
Active	A. Thermal (heating iced substrate)
	B. Mechanical (striking ice) *directly* using scrapers, sticks, rollers, cutters, etc. *at distance* using projectiles, automated robots, shock waves
	C. Mechanical (shocking the iced substrate using explosive, bending, twisting and vibrating devices.

III. PRINCIPLE OF THE NEW DE-ICING METHOD

The principle of the new twisting method studied is explained in US patent 6,518,497, (**Ref. 5**). In this method, a twisting force is applied to the ice-covered cable in the elastic domain of deformation by means of a rotating device that is gripped at an extremity through a protective sleeve while the other end is fixed. This method uses the elastic energy accumulated during twisting to break the ice bond at the ice/cable interface .

Figures 1 to 4 illustrate how the method works using an 11 mm steel-strand ground wire, covered by 2 mm of ice (**Figure 1**). First, the cable extremity coupled to the rotating device is twisted for a certain number of turns, accumulating elastic energy. A few cracks are initiated in the ice deposit induced by rising shear stresses developed at the interface between the ice and the cable (**Figure 2**). The cracks are followed by local and partial removal of ice pieces (**Figure 3**). At the end of the twisting, the cable is freed, thereby liberating the accumulated elastic energy, untwisting the cable and breaking the remaining ice deposit adhering to it (**Figure 4**). Sequences of cable twisting and releasing are repeated as often as required until all or most of the ice accumulation is removed.

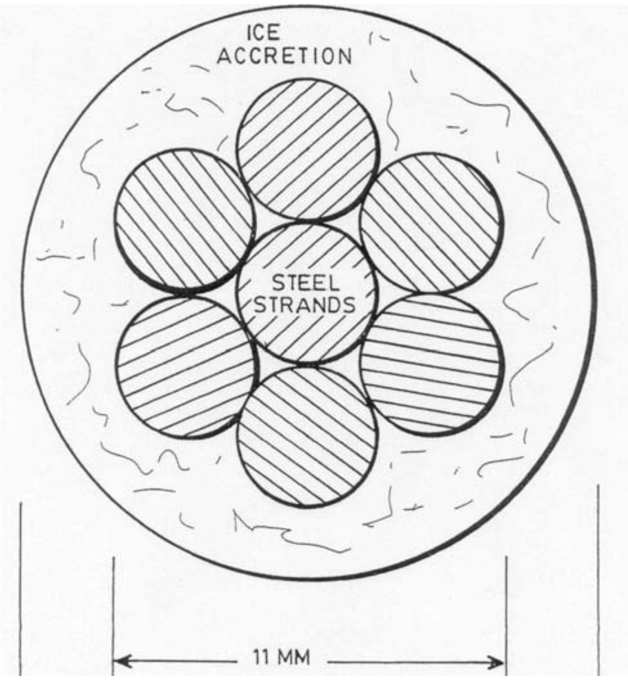

Fig. 1. 11 mm cable covered by 2 mm of ice, before rotation.

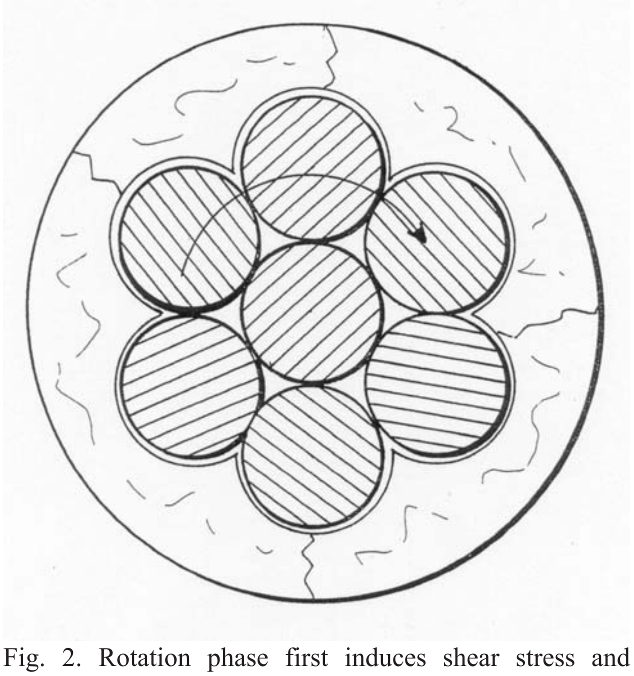

Fig. 2. Rotation phase first induces shear stress and initiates cracking in ice.

IV. EFFECTIVENESS DEMONSTRATION TESTS

The feasibility of the new method was first demonstrated in a preliminary test conducted at the end of winter, 2002 at the outdoors test site operated in the Saguenay by Déglaçage Industriel DGI (**Ref. 6**). The effectiveness of the twisting method was confirmed at the DGI test site during the winter of 2003 in a few outdoors de-icing tests conducted on a 200 m-long, 11 mm in diameter ground wire, which was slowly rotated by hand, using a rod put in mid-span. In the winter of 2004, the prototype of a hand-tool, based on the principle of the new method, was built and tested on a 15-m long artificially iced steel cable. In all these tests, ice deposits of 20-25 mm **Re** thickness and 0.85-0.90 average density were grown and removed at temperatures varying between –8 and –12 °C. The icing equipment used consisted of a commercial loader, the bucket of which was

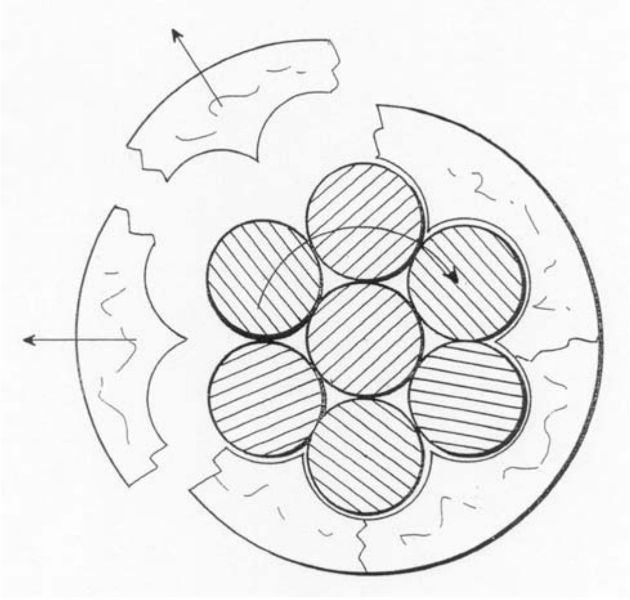

Fig. 3. Pieces of ice removed locally.

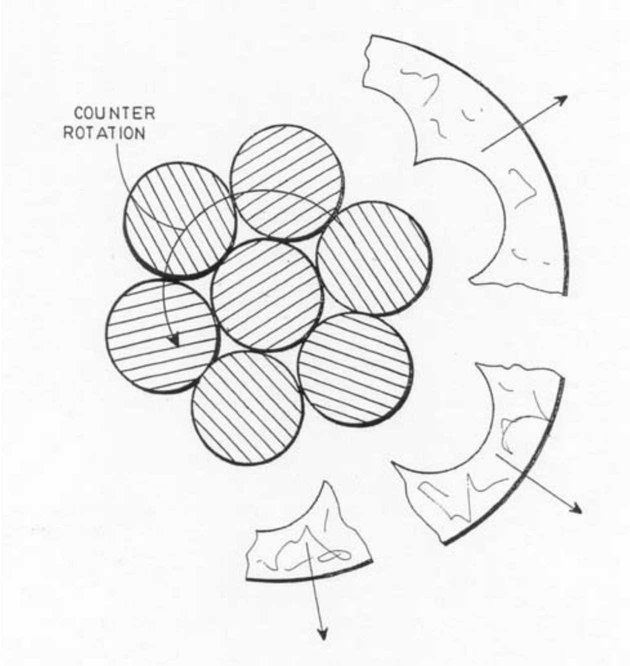

Fig. 4. Twisting elastic energy released

replaced by a steel beam, equipped with a rectangular ramp with 24 hydraulic sprayers at its upper extremity. For icing, the loader is moved along the conductors with the nozzles spraying a continuous jet of super-cooled droplets directed towards the cables. The level of the beam is continuously varied while moving, to adjust for the height variation of the iced conductors.

A. De-icing tests, winter of 2003

The photos below were taken in two de-icing tests conducted at the DGI test site on the 11 mm, 200m-long steel cable, the first on February 27 and the second on March 14, 2003. In addition to demonstrating the effectiveness of the new method, these photos illustrate the process of ice removal as the cable is rotated.

Photos 1 to 4 were taken on February 27, 2003. The de-icing operation was performed at –8 °C. The rime ice accretion had a density of 0.85. It was uniform and near cylindrical all along the cable, with a diameter of about 25 mm. The complete de-icing required the cable to be twisted twice for ten turns each.

Photo 1 shows the rod fixed mid-span, being used by the operator to rotate the iced cable. After the first rotation, the rime is seen to break into small pieces along the first few meters next to the rod.

Photo 1 De-icing along few meters at the start of iced cable rotation. (February 2003 de-icing test)

Photos 2 and 3 show broken pieces of the ice deposit in free fall following a second and a fourth cable rotation respectively. The rod device was released after ten turns. It was allowed to return in a fast spin to its initial position prior to rotation. The fast spin induced large vibrations for a few minutes, but with rather negligible ice shedding. After the vibrations were fully damped, some ice deposits still remained fixed to the cable especially at one of its attachments.

Photo 2 Pieces of ice falling to the ground following a few cable rotation. (February 2003 de-icing test)

Photo 3 Pieces of ice falling to the ground following three cable rotations. (February 2003 de-icing test)

Photo 4 shows the ice breaking observed during the second twisting sequence following the first rotation sequence of ten turns. This second sequence allowed the complete removal of all residual rime deposits close to the cable attachment. Both twisting sequences were completed in less than five minutes. **Photos 5 to 7** were taken during the March 27, 2003, de-icing operation that was performed at –12 °C. As in the February test, for complete de-icing to take place the cable had to be twisted twice for ten turns each. Ice removal was again progressive, starting at the mid-span rotation point and proceeding to the two cable attachments.

Photo 4 Pieces of ice falling to the ground during the second and final twisting sequence (February 2003 de-icing test)

Photos 5 and 6 show the pieces of ice falling to the ground during the first sequence of twisting.

Photo 5 Pieces of ice removed during the first twisting sequence (March 2003 de-icing test

Photo 6 Same as Photo 5, but a few turns later (March 2003 de-icing test)

In **Photo 7**, the removal of the last ice chunk close to the cable attachment can be seen.

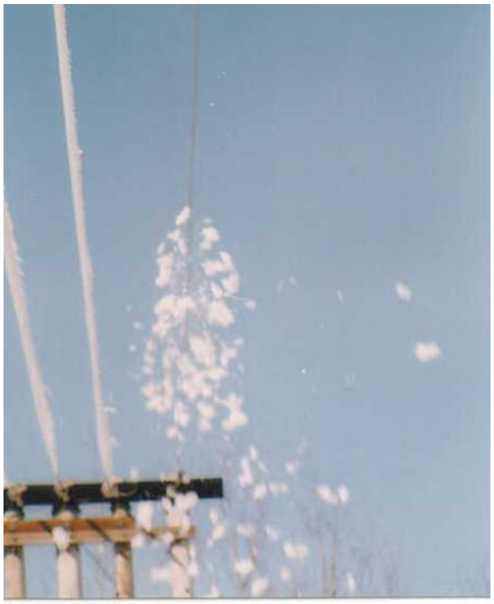

Photo 7 Pieces of ice falling on the ground during the second and final twisting sequence (March 2003 de-icing test)

As in the previous de-icing operation, twisting took less than five minutes.

B. De-icing test, winter of 2004

The following photos were taken during the de-icing test conducted at –10 °C during the first week of March 2004 on a 15 m-long 11 mm steel cable, using the hand-twisting device built specifically for de-icing following ice storms. Since the cable was 13 times shorter than the one used during the previous winter, the cable did not rotate during icing, and an eccentric ice deposit of about 25 mm **Re** thickness and 0.90 average density was formed. Complete de-icing was achieved in a fraction of turn, requiring less than one minute. **Photo 8** shows the two fixation plates of the device being screwed onto the cable at about three meters from one of its attachments

Photo 8 Plates attached by screws to the cable ensuring no damage is caused to the surface.

The plates rigidly grip the cable through two half cylindrical steel tubes. **Photo 9** shows the two handles used to rotate the cable by means of two ratchet-gears. One handle is the fulcrum and the other is for rotating.

Photo 9 Twisting device fully installed with two handles

Photo 10 shows the ice removal obtained after a few degrees of rotation. The final ice de-icing (**Photo 11**) required less than a full rotation of the cable. The total time required with the prototype twisting device was less than a minute.

Photo 10 De-icing of the 15 m long cable after a few degrees of twist. °

Photo 11 Complete de-icing in less than a full turn

V. CONCLUSION AND FURTHER RESEARCH

The exploratory research work described in this paper clearly demonstrates the effectiveness of the twisting method to de-ice overhead cables. The iced cables are gripped mid span and rotated. The twisting device can be operated either by hand or motor, depending on the rigidity of the cable. The work also highlights the potential and benefit for utilities of that new and very simple mechanical method. The main advantages of the twisting method are threefold. It does not require any sheathing, the system is installed on bare cables. The mechanical energy needed for twisting is very low, thus de-icing a span-long cable can be performed by hands in less than 2-3 minutes, as compared to 2 hours needed for the current procedure. Last, but not least, the method is safe for both operators and the environment. Finally, additional extensive research and developmental work are needed to develop practical systems based on the new method. In places where permanent anti-icing systems are required, a sophisticated automated rotating device could be installed at one of the pole attachments. The device could then twist one or two spans at the same time.

VI. REFERENCES

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Jean-Louis Laforte UQAC
e-mail: jean-louis_laforte@uqac.ca

Caroline Laforte UQAC
e-mail : caroline_laforte@uqac.ca