Development of a Portable De-Icing Device for Overhead Ground Wires

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***Abstract*—This paper presents a de-icing device, called DAC (*De-icer Actuated by Cartridge*), which aims at de-icing overhead ground wires, span by span. This is a mechanical method which consists of using a portable cylinder-piston system that creates shock waves to de-ice the cable. Since linemen cannot climb ice-covered towers, the de-icing operation is carried out entirely from the ground. First, a commercially available line-thrower is used to throw a projectile which tows a line that passes over the cable to be de-iced. Next, the DAC is pulled up to the cable and held in place by a taut rope. The DAC is equipped with a revolver barrel that stocks 6 blank cartridges that can be remotely fired from the ground. Numerous tests have been carried out to assess the efficiency of the method and to optimize the physical parameters of the device.**

I. INTRODUCTION

ATMOSPHERIC icing on overhead transmission lines may compromise the continuity of electrical energy transportation. For instance, ground wires (GWs) loaded with ice may stretch enough and get too close to phase conductors, leading to flashovers and possibly power outages. Such flashovers may also result from differential ice shedding between phase conductors and GWs. Experience shows that such problems are usually found on a very small scale, affecting only a few spans. Consequently, there is a need for a portable de-icer capable of de-icing the GWs span by span.

Thermal techniques (heating by Joule Effect) are usually applied to de-ice overhead phase conductors [1]-[4]. However, GW de-icing still remains a challenge.

Since the well-known January 1998 ice storm, Hydro-Québec TransÉnergie, the Hydro-Québec's transmission division, has started the development of new mitigation technologies to limit the impact of severe ice storms on its network. In this regard, a number of GW de-icing techniques has been proposed and developed [5]-[10]. This paper presents a portable de-icing device, called DAC, which aims at de-icing overhead GWs, span by span.

II. ICE PROPERTIES

Before presenting the de-icing method, it is important to mention some noteworthy properties of ice in order to understand its behavior and to be able to develop an optimized de-icing device.

Ice has a very complex behavior with properties that vary with the temperature and strain rates. For instance, at -2°C, glaze ice is ductile at low strain rates ($< 10^{-5}$/s) and brittle at high strain rates ($> 10^{-3}$/s) [11]. At intermediate strain rate values, it is brittle in tension and ductile in compression.

Consequently, ice is easy to break using mechanical shocks because the energy is not dissipated in plastic deformation. The energy required to break the ice is a function of its mechanical strength, which depends on its microstructure and temperature, as well as its density and volume.

Glaze ice is also very adherent, which makes it difficult to remove from the surface of the conductors or GWs.

III. DESCRIPTION OF THE DE-ICING METHOD

This is a mechanical method which consists of using a portable de-icer equipped with blank cartridges that can be remotely fired to create shock waves in the GW. These waves propagate and break the ice into small fragments.

A. Basic Requirements

The basic requirements upon which the development of the DAC is based are described hereafter. At the beginning of the R&D project, the DAC had to be:

- Installed from the ground.
- Portable, effective, safe and easy to use.
- Quickly and easily installed on the GW.
- Fired from the ground with a remote control.
- Equipped with a cartridge magazine (min. 6) for multiple firings with a selection of proper blank cartridges.
- Capable of withstanding mechanical shocks.
- Efficient enough to de-ice the GW without damaging the supporting structures and hardware.

Basically, the DAC takes advantage of the brittle property of ice to create shock waves that de-ice the GW.

B. Description of the Prototype

Fig. 1 shows a drawing of the actual prototype. At the top, the piston rod is equipped with a open-ended clamp which is firmly held into contact with the GW to transmit the force created from the firing pressure in the combustion chamber.

At the bottom, the DAC is equipped with a revolver system (Fig. 2) that stocks 6 blank cartridges in a barrel (Fig. 3). A solenoid is used to pull the trigger of the revolver system (Fig. 2). This solenoid is plugged into the electronic box which is fixed to the cylinder. Each cartridge can be remotely fired from the ground by means of a highly secure digitally encoded RF firing system, which provides reliable, interference-free operation of the DAC. The wireless firing system includes:

- An electronic circuit receiver (Fig. 4).
- A set of batteries for the electronic circuit receiver.
- A capacitor circuit that needs to be recharged before each use in order to supply the current required by the solenoid whenever the DAC is fired.
- A remote-control (transmitter) to be used from the ground to fire the DAC (Fig. 5).

The first three items are encapsulated within the aluminum box that is rigidly fixed to the cylinder.

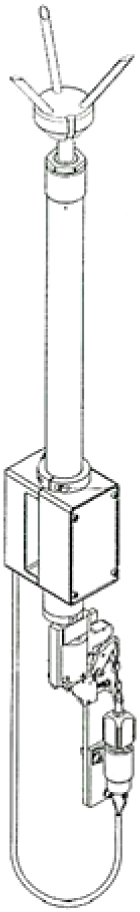

Fig. 1. Drawing of the DAC prototype.

Fig. 2. Revolver system with solenoid for multiple firings.

Fig. 3. Barrel of the revolver system stocking 6 blank cartridges.

Fig. 4. Encapsulated electronic circuit receiver inside the aluminum box.

Fig. 5. Remote control to be used from the ground.

C. Installation from the Ground

Since linemen cannot climb ice-covered towers, the de-icing operation is carried out entirely from the ground. This is a major advantage of this method.

For this purpose, a commercially available line-thrower, as shown in Fig. 6, is first used to throw a projectile which tows a pilot line that passes over the GW to be de-iced. This type of device is commonly used by Coast Guards during rescue operations.

The line-thrower stands on a sort of "launching pad" that was specifically designed for this application to withstand the substantial recoil force (5.4 kN) of the line-thrower. The inclination of the launch pad, which roughly depends on GW height and the relative position of the line-thrower, is easily adjusted by means of a tripod commonly used for land surveys (Fig. 6). As a guideline, an inclination of about 20-25° with respect to the vertical has given very good results during trial tests.

Fig. 6. Commercially available line-thrower.

Once the projectile has been thrown, a stronger rope is then attached to the pilot line and passed over the GW. The DAC is then pulled up to the GW and held in place by the taut rope as shown in Fig. 7. If necessary, a second rope may be used to guide the ascent of the DAC over the phase conductors.

Many types of ropes have been tested in wet conditions to check their electrical isolation performance in order to identify a proper type for the pilot line and the pulling rope.

Fig. 7. DAC held in place by a taut rope and ready to be fired.

D. Ice-Breaking Action

Whenever the DAC is fired, gas expands in the combustion chamber and the piston pushes the GW upwards. This is schematically shown in Fig. 8. The piston then reaches the end of its stroke and the GW is pulled down. Two symmetrical transversal waves are therefore created and propagate along the GW. As long as the waves travel, the ice accumulated on the GW breaks up into small fragments. This ice-breaking action absorbs energy from the traveling waves and reduces their amplitude. The waves eventually die out when all their energy has been absorbed in breaking up the ice. They may also reach the span extremities with enough energy to be reflected back in the span with a reverse amplitude, therefore propagating back and forth with a slowly decreasing amplitude.

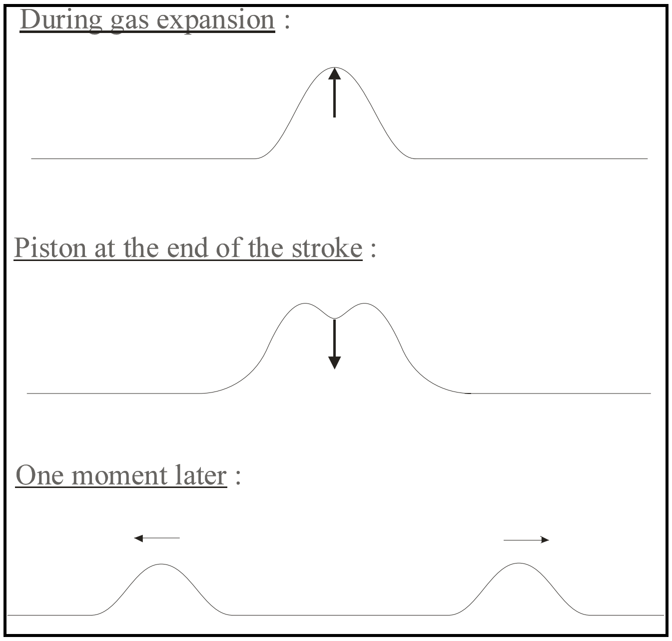

Fig. 8. Sequential motion of the GW during de-icing.

A longitudinal wave is also created together with the transversal wave during gas expansion. Its effect has been measured with a load cell located at a span extremity. This wave propagates back and forth along the span at a speed of about 4 km/s which is about 27 times faster than the transversal wave. However, this wave does not significantly contribute to the de-icing as the transversal wave does.

IV. TEST RESULTS

An outdoor 100-meter test span depicted in Fig. 9 was used for the de-icing tests. The span is equipped with a steel GW that is 12.7 mm in diameter and strung to a tension of 12.5 kN (before ice load). Tests have been carried out at temperatures ranging from –20 to –2 °C in order to characterize the device and the force transmitted to the GW as well as the resulting attenuation of the traveling wave for different ambient conditions. Some parameters of the device have been optimized in order to create an impact powerful enough to de-ice the whole test span.

Most of the tests were carried out by rigidly attaching the device three meters from the span extremity to provide sufficient clearance. This way, a single transversal wave propagates along the span and de-ices the GW. Before each de-icing test, eccentric ice accretion was artificially built up on the GW as shown in Fig. 10, with an equivalent ice thickness of 12.7 mm. This was done by slipping a plastic hose on the GW and filling it with water.

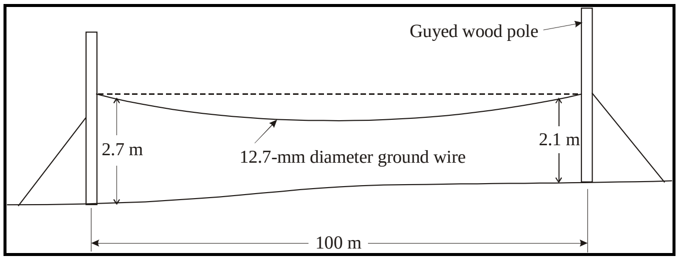

Fig. 9. Sketch of the outdoor test span.

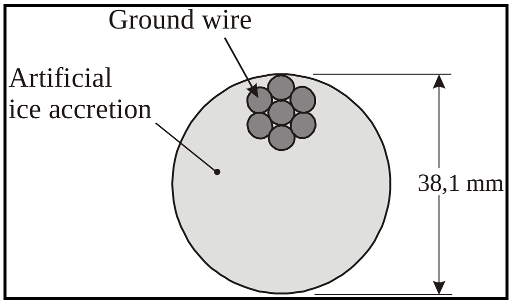

Fig. 10. Eccentric ice accretion on the GW.

Fig. 11 shows three successive photos that were taken during a de-icing test. In order to obtain clear photos, the ice had been given a red color. The propagation of the transversal wave and resulting ice breakage appear clearly on these photos.

Fig. 11. Successive photos of a de-icing test.

The power conveyed by the transversal wave decreases as it travels. This power has been measured at ¼, ½ and ¾ of the span using accelerometers attached to the GW (Fig. 12). The time integral of this power represents the energy conveyed by the wave.

During a de-icing test, the average energy lost by the traveling wave along the span is about 1.86 J/m or 2.0 J/kg of ice. A fraction of this energy (about 0.24 J/m, measured without ice) is dissipated in the cable itself through self-damping.

Fig. 12. Accelerometer installed on the GW with concentric ice accretion.

For comparison purposes, a de-icing test was also carried out with concentric ice accretion as shown in Figs. 12 and 13. Even though the ice thickness is equivalent to the eccentric case, more energy is needed to break up the ice and the average energy lost by the transversal wave is about 6 to 7 times higher. Multiple firings may be necessary to de-ice long actual spans with concentric ice accretion. This can be easily achieved by means of the revolver system.

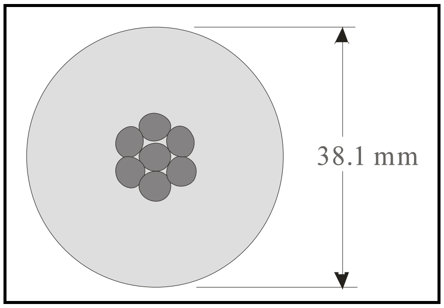

Fig. 13. Concentric ice accretion on the GW.

The physical parameters of the DAC such as the piston stroke, cylinder and piston masses, internal peak pressure, piston diameter, etc., have been optimized to efficiently de-ice two types of steel GWs with diameters of 11.1 and 12.7 mm (7/16 and ½ inch). These GWs are widely used on Hydro-Québec's transmission network.

V. APPLICATION TO OPGW

More than 4000 km of Optical Ground Wires (OPGWs) are also installed on Hydro-Québec's transmission network. These OPGWs are mainly used for data transmission between generation plants, substations and dispatching centers.

A series of tests has been carried out to validate that the shock waves created by the DAC do not disrupt the optical signal or damage the optical fibers embedded in the OPGW.

A. Optical Tests

The DAC was tested on a 450-m span of an OPGW installed at the IREQ’s full-scale test line in order to evaluate the effect of the shock waves on the optical signal. This 22.9-mm diameter OPGW is commonly used on Hydro-Québec's transmission network. For the purposes of the tests, the DAC was rigidly attached at two different locations along the span: three tests at mid-span and three tests at 3 meters from the tower. In these tests, significant bending amplitudes were recorded at suspension clamps with values very similar to those obtained during large-amplitude galloping events.

During the tests, no optical disturbances were recorded by the SONET system and no attenuation was measured by the optical power meter.

B. Endurance Tests

Endurance tests were also carried out to ascertain that the use of the DAC does not damage the OPGW or the optical fibers. A special 60-m test span of an OPGW was installed at a height of 2 m above ground with the DAC rigidly attached at mid-span. During these tests, the DAC was fired for 100 shots in the same day and the attenuation of the optical signal was continuously monitored. An attenuation increase of 0.011 dB/fiber was recorded, which is not significant.

At the end of these tests, the OPGW was removed and cut out at mid-span and at both extremities for inspection and dissection. No damage to the optical fibers or to the constituent wires was reported.

C. De-Icing Test

A de-icing test was also carried out to check whether the DAC could efficiently de-ice an OPGW strung on the test span shown in Fig. 9. Results revealed that it is more difficult to de-ice an OPGW than a steel GW because of its higher mechanical impedance. This has the effect of reducing both the vertical displacement of the piston and the amplitude of the transversal wave. Multiple firings may be necessary for actual spans of OPGWs.

VI. STRATEGY FOR USING THE DAC

The strategy for using the DAC consists in de-icing the GW after a flashover between the GW and the phase conductors. In such a case, the transmission line must be de-energized and a line crew is sent to the site where the flashover occurred. The de-icing operation with the DAC is then carried out entirely from the ground with minimum risk to the line crew. The strategy could eventually evolve to GW de-icing on live lines but this was not a requirement at the beginning of the project.

The use of the DAC, span by span, creates unbalanced loads at the supporting structures. Such loads may be substantial enough to lead to the slippage of GW at suspension clamps or to damage the ground-wire peaks. Therefore, they must be taken into account prior to the de-icing operation.

For this purpose, it is planned to use a strong rope that would be passed over the GW together with the rope used to ascend the DAC. This rope would be temporarily anchored to the ground at mid-span in order to retain the GW from freely moving up during the de-icing operation. This would prevent substantial unbalanced loads to be transmitted to the supporting structures and could be worked out for a number of suspension spans within a line section.

VII. CONCLUSION

A mechanical de-icing device (called DAC), which aims at de-icing GW and OPGW span by span, has been presented. This device takes advantage of the brittle property of ice at high strain rates to create shock waves that propagate along the span and break the ice. The DAC is a portable, robust, effective and simple device that can easily be used after a line fault due to clearance violation between GWs and phase conductors. The de-icing operation is carried out entirely from the ground, which represents a major advantage.

The project is currently at the industrial stage and the first industrial models are expected to be available by the end of 2005. In the meantime, the prototype, which has successfully endured more than 250 shots, is ready to be tested under field conditions.

VIII. ACKNOWLEDGMENT

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