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Ice Shedding of 200 m-Long Artificially Iced Overhead Cables at an Outdoor Test Site

Jean-Louis Laforte*, Marc-André Allaire**, and Daniel Gagnon ***

*Université du Québec à Chicoutimi, Chicoutimi, QC, Canada, G7H 2B1
**Déglaçage Industriel DGI Inc., Chicoutimi, QC, G7G 2V7
***Institut de Recherche en Électricité du Québec IREQ, Varennes, QC, Canada, J3X 3S1

Abstract – **This paper presents two shedding events in which three 200m-long segments of line conductors were artificially iced under cold conditions, after which they were allowed to naturally shed when warmed in air above 0 °C. Two of the cables consisted of round-strand ACSS and ACSR conductors, 19 and 22 mm in diameter respectively. The third cable was a ACST-TW COMPACT conductor, with trapezoidal strands, 19 mm in diameter. In the line set-up, each conductor was equipped with a load cell. These monitored the variations in tension due to the ice load, both during and following icing, by means of a real-time data-logging device. In this study, the compact conductor with trapezoidal strands was observed to shed first. It also had the shortest shedding time, 90% of the ice deposited had fallen after 1.5 hrs as compared to 3 and 4 hrs for the two round-strand conductors. Both shedding cases exhibited the two classic mechanisms of ice shedding: ice sublimation/evaporation, when air was below 0 °C, and ice melting and break-off when air was above 0 °C. Most interestingly, this field study found a third active shedding mechanism, that of ice sliding. This type of mechanical shedding, to the best of our knowledge not previously mentioned, made the melting mechanism more effective. It came into effect after some ice pieces had already fallen to the ground, allowing ice deposits located at higher positions to slide down along the cable and strike other pieces of ice or any obstacle positioned below. The impact then broke the ice pieces into smaller parts, allowing them to fall to the ground. This particular mechanical mode of shedding explains why, under the same warming conditions, a cable or a conductor with a smooth surface, such as one with trapezoidal strands, may take less time to shed than a round-strand conductor, which has a rougher outer surface.**

I. INTRODUCTION

It is rather difficult to study the behaviour of iced overhead cables on actual electrical lines because of the low occurrence of icing events and their random character. It is also difficult to reach the most exposed sites making measurement campaigns very expensive. This partly explains the paucity of field-collected data presently available on the behaviour of ice-covered overhead conductors and ground cables, especially on shedding following natural ice events. Even if laboratory simulations can adequately duplicate ice conditions, they are mostly limited to a small number of tests performed on short cable; moreover, neither sag nor elasticity can be duplicated. On the other hand, the winter operation of an easily accessible outdoor experimental line, with a length approaching that of a real span, allows the growing of artificial ice deposits representative of those formed in the field. A great number of very severe ice episodes can be simulated outdoors during a single winter season. It allows the gathering of a large quantity of icing data in a relatively short period of time. In fact, it would take dozens of years to duplicate the same quantity from overhead cables of actual lines. For this reason the Institut de recherche en électricité du Québec (IREQ) contracted Deglaçage Industriel DGI Inc. to run artificial icing tests in cold conditions at its existing outdoor experimental site.

The objective of this paper is to describe two of the shedding events observed at the outdoor site following artificial icing tests carried out on three 200m-long segments of power line conductors. In both cases, shedding was observed when the iced conductors were exposed to air above 0 °C. Both artificial icing tests were part of an IREQ sponsored project involving seven artificial icing tests conducted during the winter of 2003 to compare the effect of ice accretion rotation as well as the damaging effects of large ice accretions on conductors actually in service (**Ref. 1**). A large accretion is defined as having over 30-35 mm Radial

Equivalent (**Re**) thickness. **Re** is calculated from the mass of ice accumulated per unit of length on the cable segment, assuming that the entire ice deposit is cylindrical. The objectives for studying the two shedding events were twofold. First was to determine the weight loss of ice deposits under day-night temperature variations following ice accumulation and second, to see if there is a difference in ice removal rate between round and trapezoidal strand conductors.

II. CONDUCTORS, ICING, AND RELATED MEASUREMENTS

The overhead conductors that were artificially iced prior to shedding were the three 200-m long segments numbered 2, 3, and 4 (**Figure 1**).

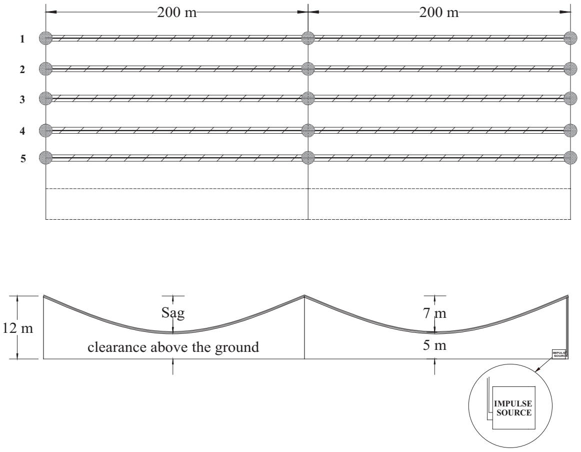

Fig. 1 Schematic of the 200m-long conductors installed at the DGI experimental site.

Two standard round-strand conductors, a 19 mm diameter ACSS, and a 22 mm diameter HAWK ACSR were installed in positions 2 and 3. The third conductor, a 19 mm diameter COMPACT ACSR/TW-AW with trapezoidal strands was installed in position 4. The icing equipment consisted of a commercial loader, the bucket of which was 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 span 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. The height of the conductors varies depending on the position along the span. It also decreases as ice deposits grow and mechanical loads increase.

In the test line set-up, all the three conductors are equipped with load cells at the west pole attachments (at left in **Fig. 1**). These record in real time the variations in tension due to the weight of the accumulated ice during and following icing. The air temperature is also recorded in real time by means of the same data acquisition system, using a thermocouple located next to one of the load cells. During the artificial icing of the conductors, wind speed and direction were also measured, but at periodic intervals. The weight increase due to the ice load was estimated from the increase in the cable tension measured by the load cells, the latter being divided by a proportionality factor close to three.

III. SHEDDING OBSERVATIONS

A. First event

The first shedding occurred during artificial icing test no. 5, which was performed on Thursday, February 27 and Friday, February 28, 2003. During the icing period, which lasted ten hours and fifteen minutes, temperatures varied between –15 and -1 °C. The latter value was observed at 14h10, when spraying had to be stopped because the ice deposits begun to melt. At this point shedding had begun. During the icing period, wind was from the Northwest with maximum and minimum speeds of 7 and 1 km/h respectively. Under these conditions, ice grown on the three conductors was a clear and transparent glaze with a density of 0.90. Shedding activity stopped at the end of the afternoon, when temperatures dropped below 0° C. At that time, the three conductors remained ice-covered, only a part of the ice deposits having been shed. Some insignificant shedding continued during the weekend, when temperatures reached 0 °C on Sunday. On Monday, ice deposits were broken off using hand tools so that a new icing test could be started as soon as possible.

As the ice removal was incomplete, this first event can be considered as one of partial shedding. **Photo 1** illustrates the partial shedding on all three lines, showing large pieces of ice from the middle of the span just after break-off. **Photo 2** shows the three conductors as photographed at the end of the afternoon at which time they were still partly ice-covered, but after the temperature dropped below 0 °C.

Photo 1 Ice deposits in free fall (first event)

Photo 2 View of partly shed conductors (first event)

It is clear in the illustration that conductor 4, with trapezoidal strands positioned at left, which has collected the greatest amount of ice, has shed its deposit at a faster rate than that of the two round-strand conductors. This visual observation agrees with the variations in mechanical tension observed in real time during the shedding period by the load cell logging system (**Figure 2**). Using data from **Figure 2**, it is possible to calculate the ice load loss that the three conductors had in the same period of time: 38 % for the COMPACT, 13 and 12 % for the two round-strand conductors, respectively.

B. Second event

The second shedding event was observed following artificial icing test no. 7. It ran from March 11 to March 14, 2003. In this test, icing took four days to complete. Total icing time was 18 hours and 40 minutes. Temperatures varied between –12 and 0 °C, averaging -6 °C during the icing period. During the four-day icing phase winds came from two directions, Northwest and Northeast, with maximum and minimum speeds of 10 and 22 km/h respectively. Under these conditions, ice grown on the three conductors was a clear and transparent glaze with a measured density of 0.90 ± 0.02. Short icicles formed during icing. This kind of ice is typical of glaze deposits formed in a wet regime.These glaze deposits were slightly eccentric, the measured mean Re thickness was 28 ± 4 mm.

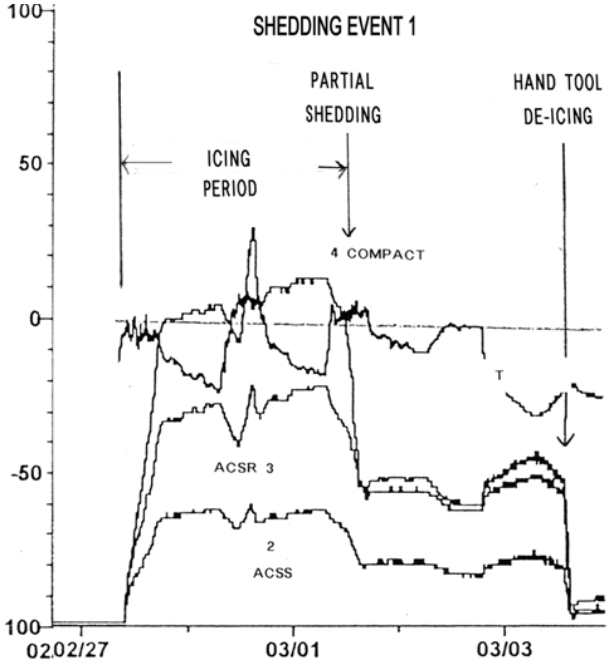

Fig. 2 Mechanical tension and temperature recordings of the first event

Ice deposits were not removed as planned at the end of the icing period, as above freezing temperatures were forecast for the next two days. The ice deposits were left exposed to the warming temperatures to study how the three conductors would shed their ice. However, temperatures remained below 0 °C for the following five days. It was only on the sixth day that the iced conductors were exposed directly to the sun and above zero temperatures. The conductors then finally shed all ice deposits in the middle of the day.

Figure 3 shows the temperature and mechanical tension recordings of the second event. They were monitored in real time by the load cells from the end of icing on Friday March 14, 2003 to final beak-off on Thursday, March 20, 2003. Using the data presented in **Figure 3**, it is possible to recreate the main stages of the whole shedding process, from the end of the icing phase to the final break-off.

Three processes were observed. The initial phase of shedding lasted a little over six days, going from the cessation of artificial icing to the middle of the day, Thursday, March 20, 2003.

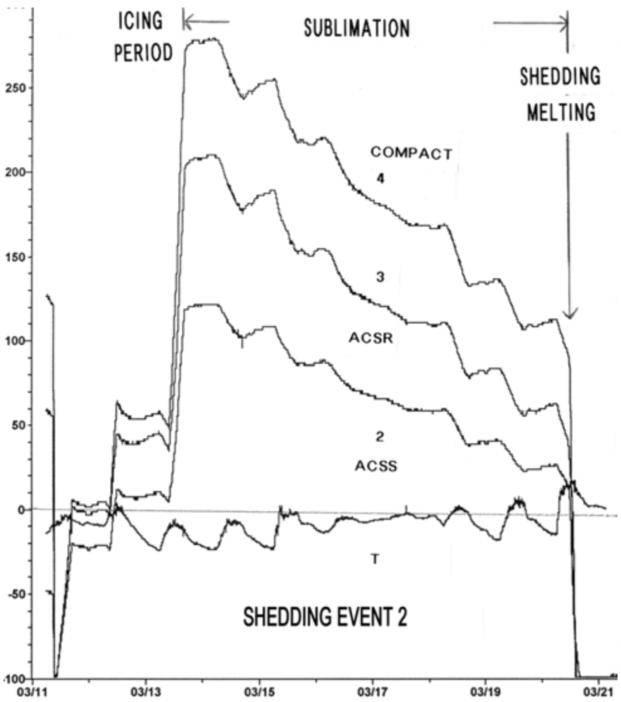

Fig. 3 Temperature and mechanical tension recordings of the second event from the end of icing to final beak-off

During this period, temperatures remained below 0 °C. Under such conditions, the ice covering the three conductors could only sublimate or evaporate into the surrounding air, without any ice melting or break-off . Day after day, this evaporation steadily decreased the mechanical tension in the three conductors (**Figure 3**).

The final phase of shedding occurred on Thursday, March 20, 2003 when temperatures rose above 0° C. At this point the ice deposits begun to melt and the first break-off took place. There were both liquid water and pieces of ice falling to the ground.

Data collected during the final phase of shedding with ice melting and break-off (**Figure 4)** shows that once again the COMPACT conductor with trapezoidal strands, even if it has collected a greater amount of ice than the two others, took much less time to shed as compared to the two round-strand cables. In fact, 90 % of the ice deposits of the COMPACT conductor had fallen to the ground after 1.5 hrs, as compared to 3 and 4 hrs respectively for the two round-strand conductors subjected to the same environmental conditions above 0° C.

IV. SHEDDING MECHANISMS OBSERVED

Both cases show the two main mechanisms involved in the complete conductor shedding process as it occurs in the field: ice sublimation/evaporation when the air is below 0 °C, complemented by ice melting when the air rises above 0 °C. Shedding by sublimation occurs without any ice break-off or melting.

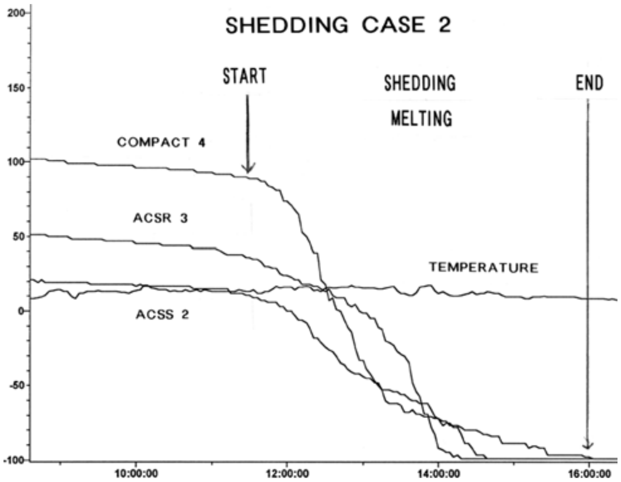

Fig. 4 Temperature and mechanical tension recordings of the second event in the final step of shedding involving melting and break-off

The melting phase corresponds to the final step of the shedding process. Indeed, this phase is often considered as the shedding itself. During melting a liquid water film forms on the surface of ice and conductor, and the ice deposit becomes free to rotate. Eccentric ice deposits first rotate to adjust the centre of gravity, then beginning at the centre of the span, water covered ice deposits break off in large pieces, which then fall to the ground.

However, there is a third process that helps make the above melting mechanism more effective, one involving sliding and mechanical shock. After the initial ice pieces fall to the ground, ice deposits located at higher positions begin to slide down along the conductor toward the middle of the span to strike and shock other pieces of ice or an obstacle positioned at a lower level.

This third, mechanical, mechanism was clearly observed in the present study. The mechanical shedding is illustrated in **Photos 3 and 4**. They show falling pieces of ice created mid-span by two pieces of ice deposits sliding along the conductor from opposite directions. In both shedding cases described, the COMPACT conductor with trapezoidal strands was observed to shed first, and had the shortest shedding time.

This particular mechanical mode of shedding can explain why, under the same warming conditions, a cable or a conductor with a smooth surface, such as one with trapezoidal strands, may take less time to shed than a round-strand conductor, which has a rougher surface.

Photo 3 Ice deposits sliding and shocking in the midlle of the span

Photo 4 Same as Photo 3 but a few second later

Even if the observations presented in this paper are limited, being supported by only two shedding events, they highlighted the great importance of the surface finish of a conductor to improve the mechanical shedding following the melting and break-off of the first pieces of ice. Under this aspect, conductors with trapezoidal strands seem to be strongly favoured by comparison to those with round strands because of their much smoother surface, on which ice deposits can slide more easily.

V. CONCLUSION

The two shedding events described in this paper highlight the potential and benefit for utilities. By using outdoor experimental test lines for studying icing and shedding behaviour under very severe artificial icing conditions, much useful information is gained in a reasonable length of time. Such icing studies on real lines would require many years of observations before a significant number of such ice events leading to ice accretions of Re higher than 25 mm would be obtained. The specific observations made in the two shedding cases demonstrate the two classic mechanisms involved in conductor shedding: evaporation when the temperature is below 0 °C, and ice melting and break off when the temperature is positive. However, the most interesting observation made during this shedding study is the important role mechanical action plays in shedding. Mechanical shedding occurs when ice deposits located at higher positions on the conductor begin to slide down along the cable to come to strike the other pieces of ice, or an obstacle positioned below. At this point they are broken into smaller parts and fall to the ground. Finally, it is this mechanical action that explains why, under the same warming conditions, a cable or a conductor with a smooth surface, such as one with trapezoidal strands, may take less time to shed ice by melting than a ACSS or a ACSR round-strand conductor, which has a rougher surface.

VI. ACKNOWLEDGMENTS

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VII. REFERENCE

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Jean-Louis Laforte
Université du Québec à Chicoutimi
Département des Sciences appliquées / LIMA
555 Boulevard de l'Université
Chicoutimi, QC G7H 2B1

phone: (418) 545-5047,
fax: (418) 545-5012
e-mail: jean-louis_laforte@uqac.ca

Daniel Gagnon
Institut de recherches de l'Hydro-Québec
1800 Montée St-Julie
Varennes, Québec, J3X 3S1
phone: (450) 652-8396
fax: (450) 652-8181
e-mail: gagnon.daniel@ireq.ca