Ice accumulation at measuring site Hallormsstadahals

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Abstract — This paper presents results from icing measurements obtained at Hallormsstadahals in eastern part of Iceland. The measuring site is located 575 m.a.s.l. where ice accretion occurs frequently every year. The ice load measurements are obtained from three 80 m long test spans and from two suspension towers in parallel 400 kV OHTLs situated approx. 300 m from the test spans. One of the OHTL has duplex conductor while the other OHTL has a simplex conductor. The abovementioned suspension towers (one in each line) are equipped with a load cell in one phase conductor attachment point. Many icing events have been records in the area, with ice loading in the range of 50-200 N/m. The highest measured loading to date is 370 N/m in a test span.

Comparison of the maximum ice load recorded by the different measurement units is presented. This comparison includes: (i) comparison of simplex and duplex conductor. (ii) comparison of different conductor diameters. (iii) comparison of icing in 400 kV OHTL and 80 m long test span, both equipped with a 49.9 mm conductor.

The comparison is focused on in-cloud icing with loading in range of 50-350 N/m. It revealed that the simplex conductor is more prone to extreme icing than each of the duplex sub-conductor. Accretion rates were not found to be markedly different between 18 mm, 28 mm and 49.9 mm conductors but smaller conductors often experience more extreme loading due to less frequent ice shedding. Reasonable correlation was found between OHTL and test span. Ice shedding was found to have noticeable influence on the maximum loading and is often a critical factor.

I. Introduction

Ice load measurements were initiated at Hallormsstadahals, in the year 1983, and have been continuous since then. The site is located in the eastern part of Iceland, on a mountain ridge where heavy ice load is frequent. A 132 kV transmission line (FL2) has been operated in the area from 1980 and has since experienced frequent icing and many operational disturbances due to icing. An automatic weather station was installed at the site in 1996 (Fig 1). The station is monitored online.

Two parallel 400 kV overhead transmission lines (OHTLs) were constructed in the area in 2006. Due to the severity of icing, one of the lines was fitted with simplex conductor in the most exposed icing areas while the remaining part of both lines have duplex conductor. On-line measuring and monitoring system was installed in one suspension tower in each line. It consists of load cells with data loggers and video cameras.

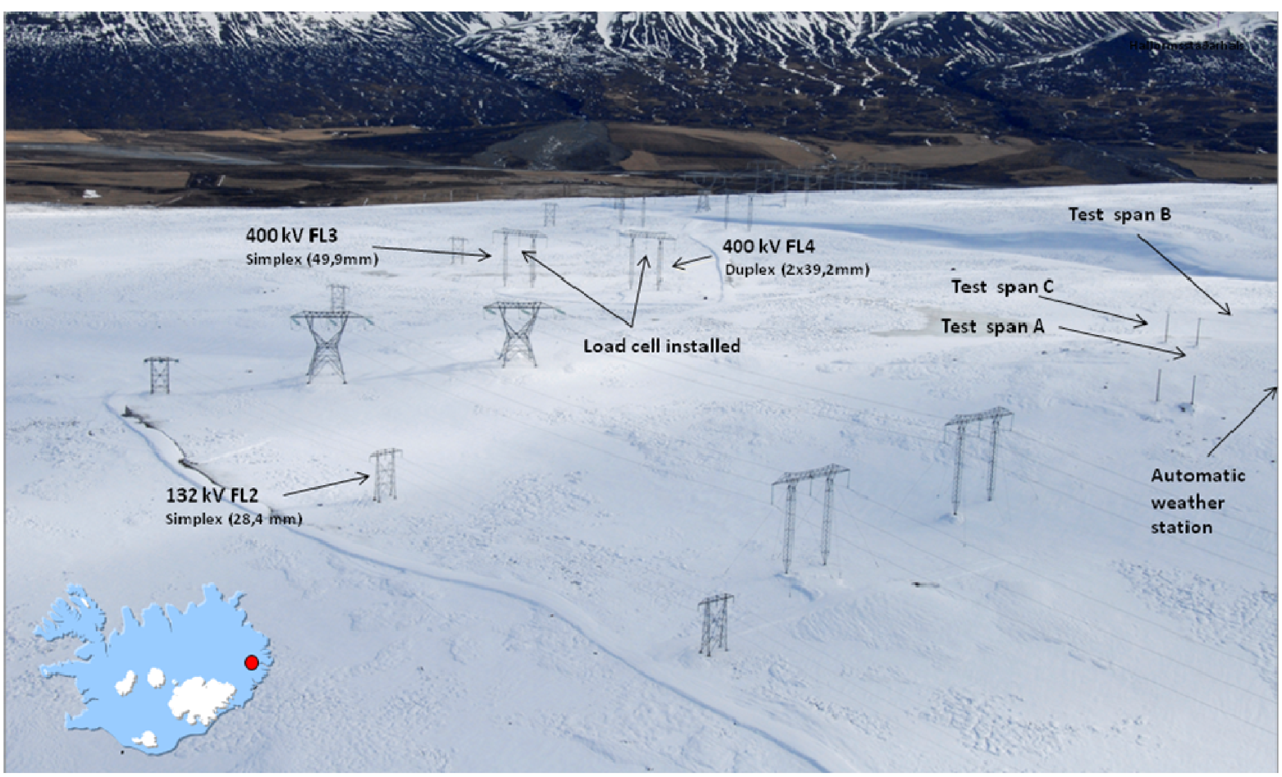

Fig. 1. Hallormstadahals, measuring site with 3 test spans and measurement in two suspension towers in 400 kV OHTLs.

II. Description of Site and Measurement Units

The measuring site is located between two narrow valleys facing north-northeast (Fig. 2 and Fig. 3). The distance to the coast in this direction is 65 km. Most icing events at this site occur with wind blowing from north-northeast along a 10-15 km wide topographical canal, which is almost flat from the coast until approximately 10 km from the test site. From that point onwards, which is only 50 m.a.s.l., the land rises continuously up to the test site at 575 m.a.s.l. and further up to 1000 m.a.s.l., 10 km behind the site. The distance to coast heading east is shorter, only 20 km to the nearest fjord bottom. In this direction, the site is sheltered by a mountain ridge reaching above 1000 m.a.s.l. Thus icing events are not frequent when wind is blowing from east. Most icing events in this area are in-cloud icing, but wet snow icing occurs also. Freezing rain is very rare.

The climate at Hallormsstadahals is characterized by cold and relatively dry winters, compared to the more humid and warmer coastline. The path of low clouds and humid air is open to wind blowing from between north and northeast. Wind from northeast is the prevailing wind direction after the most frequent southwest-direction, which brings dry air and mainly cloud free sky.

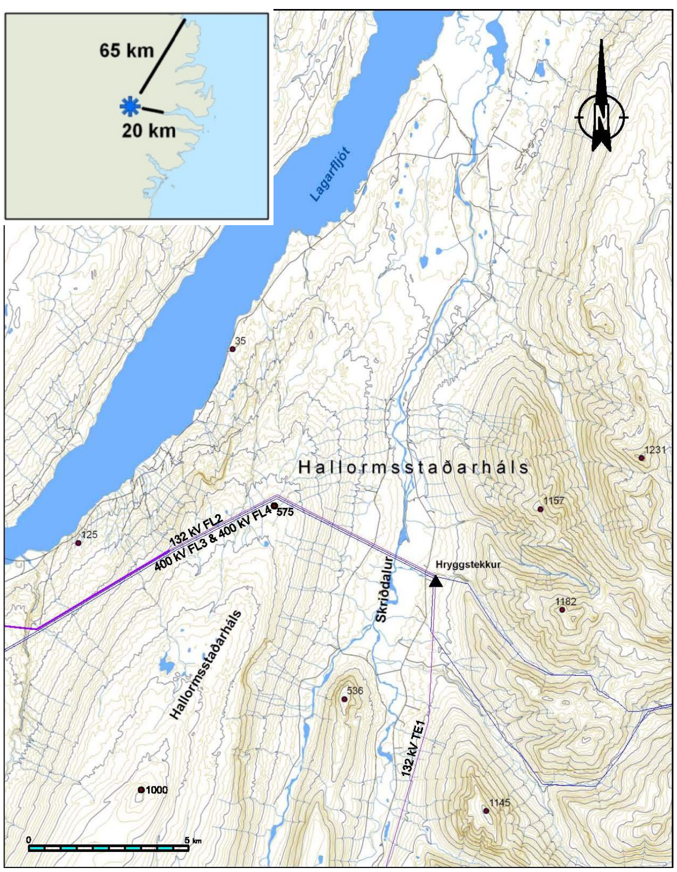

Fig. 2. Hallormstadahals, measuring site with test spans and OHTLs

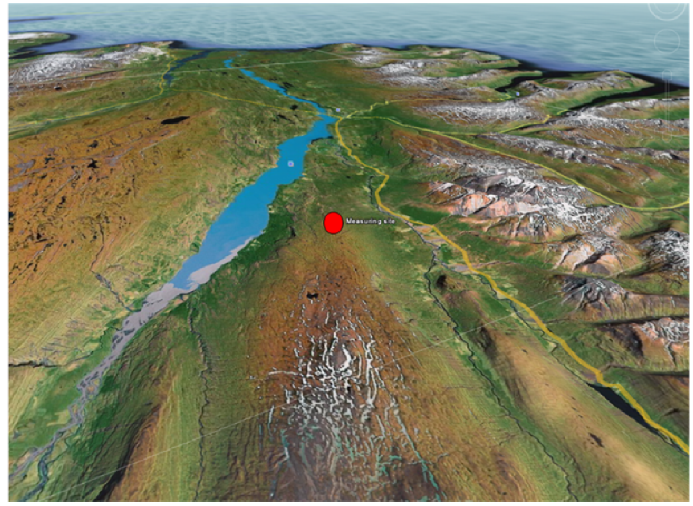

Fig. 3. View over Hallormsstadahals in NNE direction. Distance to shore is 65 km. The site is unsheltered in this direction.

The units of operating measurements at Hallormsstadahals are as follows:

- ***Test span A***: 80 m long, installed with 28.1 mm AAAC conductor. Span direction is 120° (True). 575 m.a.s.l. Operated continuously since 1983.
- ***Test span B***: 80 m long, installed with 28.1 AAAC conductor. Span direction perpendicular to span A, i.e. 30° (True). 575 m.a.s.l. Operated continuously since 1983. Span B and span A share one pole.
- ***Test span C***: 80 m long, parallel to span A, located 10 m to northeast. 575 m.a.s.l.. The span was installed 1992 on same poles as test span A but 1.5 m lower. In 1996, separate poles were erected for test span C. The span has been operated continuously since 1992 with different setup of conductors: (i) 1992–1997 with 28 mm AERO-Z smooth conductor. (ii) 1997–1999 with 18 mm AAAC conductor. (iii) 1999–2007 with 28 mm AAAC conductor. (iv) from 2007 with 49.9 mm AACSR conductor.
- ***FL3-400kV OHTL***. Simplex phase conductor (49.9 mm AACSR). Load measurements are obtained in a suspension insulator chain. Direction of the line is 117° (True). Height is 540 m.a.s.l. with conductor attachment at 19 m above ground. Spans are 205 m and 192 m. Distance to test spans is ~325 m. Ice measurements started in 2006. The OHTL was energized in Jan. 2007.
- ***FL4-400kV OHTL***. Duplex phase conductor (2x39.16 mm AACSR). Load measurements are obtained in a suspension insulator chain. Direction of the line is 117° (True). Height is 545 m.a.s.l. with conductor attachment 19 m above ground. Spans are 175 m and 192 m with 4 spacers per span. Distance to test spans is ~272 m. Ice measurements started in 2006. The OHTL was energized in in Jan. 2007.
- ***Automatic weather station*** measuring temperature, wind direction, wind speed and humidity. Wind measurements are of limited use in severe icing events since the anemometer is not heated. It has been operated continuously since 1996.

Fig. 4. Test spans seen from measuring towers in the 400 kV OHTLs.

In the test spans, the conductors are strung on wooden poles 10 m above ground. End tension measurements are made with load cells connected with data loggers. The tension recorders measure tension at 0.5-1 Hz and store maximum, minimum and mean values at 10 minute intervals. Mechanical dynamometers are also installed to give maximum value in case of failure of the electronic force recorders. Ambient temperature measurements are obtained every 10 minutes at the same height above ground as the conductors.

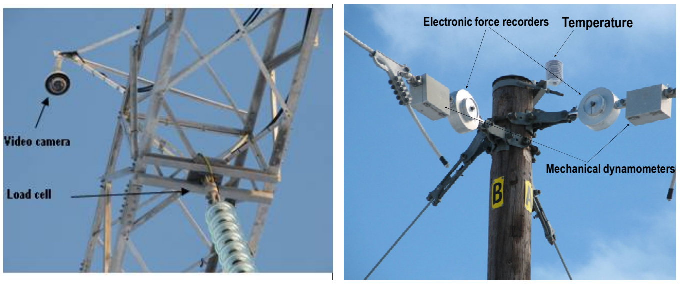

Fig. 5. Measurement equipment. OHTL to left and test span to right

The measurements of the conductor's end tension are obtained in test spans, values are converted into external load per unit length, using the geometry of the test span and mechanical properties of the cable and guys. It is assumed that loading is equally distributed along the span.

Load measurements in the 400 kV lines are obtained with a load cell fitted between the tower bridge and the insulator string of the middle phases. A reading is taken from the instruments every 5 minutes, and registered if different (by a certain tolerance value) from the last registered value. The data series registered is then converted to a 10 minute maximum, minimum and mean value data series for analysis and comparison to the test span series.

III. Description of Icing at Hallormsstadahals

Ice accumulation is frequent every year at Hallormsstadahals. The period with ice on test span A is on the average 51 days per year (annual summarized) and has varied between 10 to 75 days in the last years. The annual summarized duration of accretion has varied between 4.5 to 39 days with an average of 23 days per year (Fig. 6). This leads to classification of the severity of icing to site icing index between S4 and S5 according to the EUMENTNET/SWS II classification system as presented in [3], i.e. icing severity classified between strong and heavy.

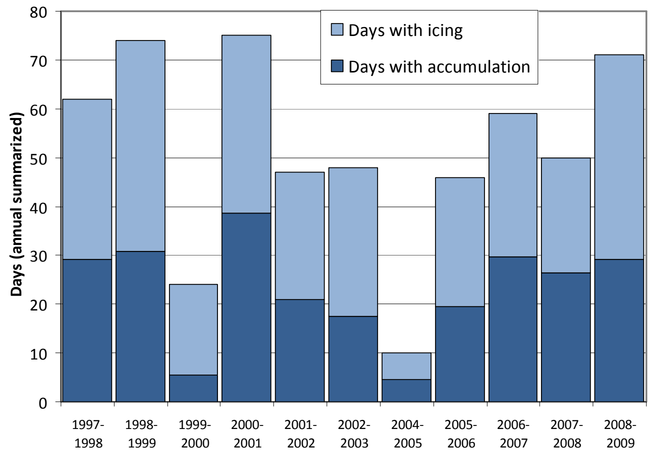

Fig. 6. Icing in test span A. Accumulation time and time with icing (annual summarized).

The icing type at Hallormsstadahals is most often in-cloud icing, with an average temperature of -3.6°C at the time of ice accretion with a standard deviation of 2.2 °C (Fig. 7). Ice shedding occurs at a wide temperature range, at an average of -1.8 °C with a standard deviation of 2.7 °C. Fig. 8 shows the relationship between ice shedding and temperature, where shedding is given as the reduction of ice load within 10 minutes. The peak load reduction event in Fig. 8 is shown in more detail in Fig. 18.

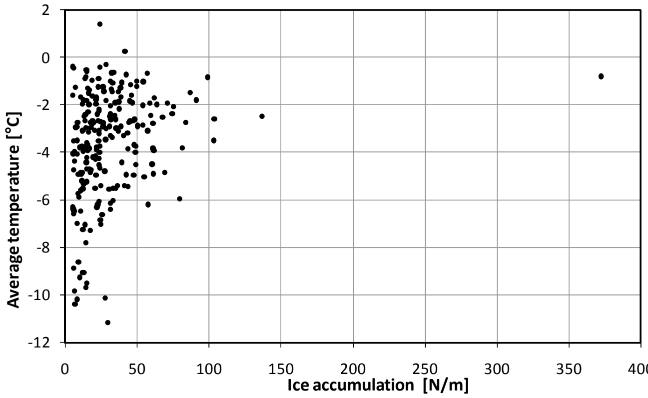

Fig. 7. Average temperature at the time of ice accumulation in test span A.

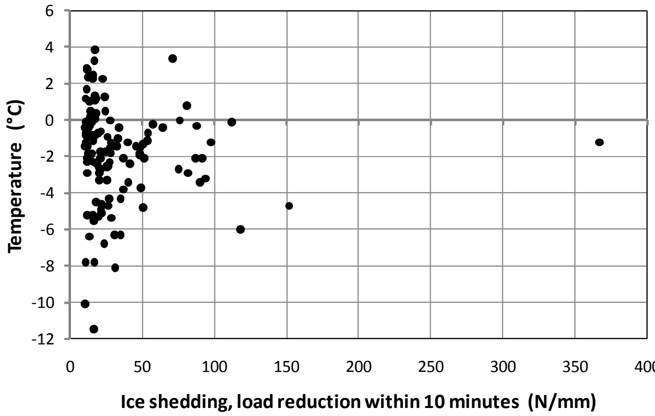

Fig. 8. Ice shedding in test span A, period 1997-2009.

Maximum icing has been measured continuously for 25 years in test span A. Maximum measured icing is 370 N/m. Fig. 9 shows the maximum measured load for each year.

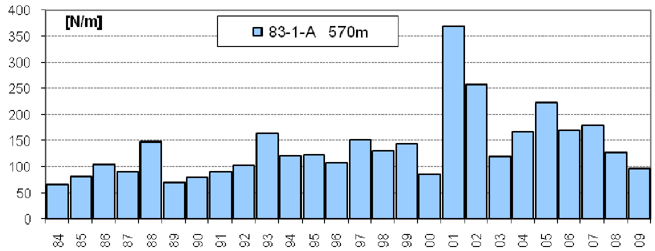

Fig. 9. Annual maximum ice load in test span A, incl. conductor weight

Fig. 10. In-cloud icing in a 132 kV OHTL at Hallormstadahals.

Fig. 11. In-cloud icing on guy wire in a test span at Hallormsstadahals.

IV. Comparison of Measured Icing

The icing measurements at Hallormsstadahals were initiated to quantify extreme ice load. With time, the installment of more measuring units then provided the opportunity to use the measurements to compare and study icing phenomena in test spans and OHTLs. Many icing events have been recorded with loading in the range of 50-200 N/m and the highest measured loading is 370 N/m in test span A. Most of the recorded events are from the three test spans that have been operated since 1983. Number of icing events have recently been recorded in operated OHTL, where measurements started 2006.

Examples of measured icing at the five different measuring units at Hallormstadahals during the period 12.Nov.–21.Dec. 2006 are shown in Fig. 12. The maximum measured ice load was 240 N/m and it occurred on the 49.9 mm simplex conductor in FL3, 400 kV OHTL. Icing occurred at same time in all measurement units but the rate of accretion and especially the ice shedding process differed.

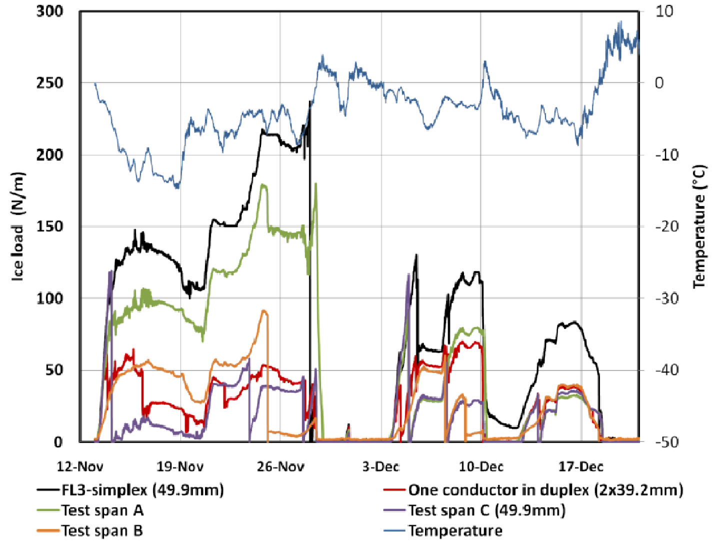

Fig. 12. Ice load measurements obtained at Hallormsstadahals in the period 12 Nov. to 20. Dec. 2006.

In following, a comparison of ice load in measured icing events is made on the influence of: (A) conductor diameter, (B) simplex versus duplex conductor in 400 kV OHTLs and (C) test span versus OHTL (same conductor).

A. Comparison of simplex conductor (49,9mm) to duplex conductor (2x39.1mm) in 400 kV OHTLs, FL3 and FL4

Ice accretion loads on single and bundled conductors are of interest to transmission line engineers. Especially in heavy icing areas (e.g. with ice load > 150 N/m) where it is of importance to know how a bundle conductor collects icing compared to a single conductor. In many countries, single conductors are used in such areas in the belief that they accumulate less icing than bundle conductors, and experience less severe galloping. Examples of countries where such an approach has been used are Norway, Canada [1] and Iceland.

A comparison of maximum measured ice load in the parallel 400 kV OHTLs (FL3 and FL4) is shown for 16 icing events in Fig. 13. FL3 is installed with a simplex conductor (49.9 mm) while FL4 has duplex conductor (2x39.2 mm). Loading for the duplex is presented for a single sub-conductor. Results shows that the simplex conductor experiences in general higher load than each of the duplex sub-conductor. In less severe icing events (up to 50 N/m) the simplex conductor experiences only a moderately higher loading but in the more extreme icing events, the difference increases to a factor of 2 to 4.

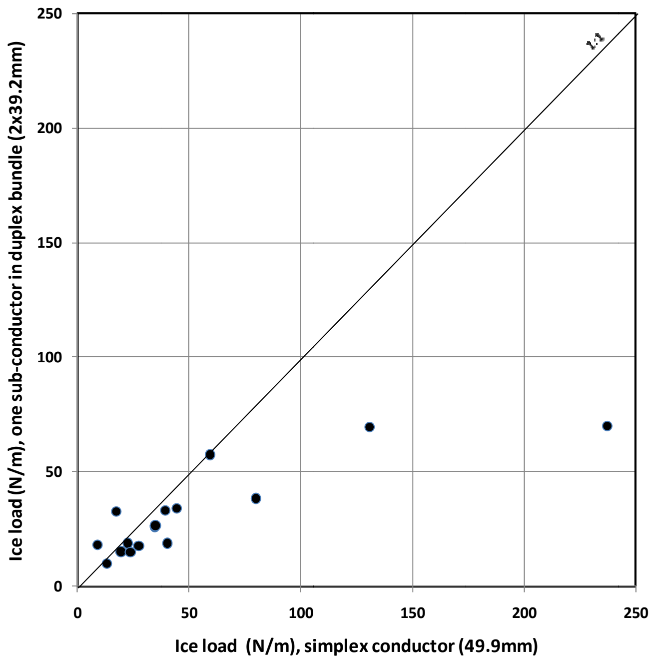

Fig. 13. Comparison of ice load on simplex conductor (49.9 mm) and one sub-conductor in duplex conductor (2x39.2 mm). Measurements are made in 400 kV OHTLs (FL3 and FL4).

Loading curves for the two most extreme events are presented in Fig. 14 and Fig. 15. Fig. 14 shows an event where the accretion rate is almost identical up to 70 N/m, but the simplex conductor experiences higher loading from that point on. Ice shedding of the bundle conductor has an impact on the comparison as ice partly falls off the duplex conductor. A similar pattern is seen in Fig. 15 where the accretion rate is similar to start with, but ice shedding of the duplex conductor leads to considerable less maximum loading. It is interesting to note the differences in ice accretion during the period 7-9 December 2006, with ice building up on the simplex but only with limited increase on the duplex. From Fig. 13 to Fig. 15 it may be argued that the duplex conductor exhibits an upper threshold limit of ice load at 70-80 N/m, while the simplex conductor does not appear to be bound by such a limit. More events are needed to verify the hypothesis. An example of ice shape of the duplex conductor is shown in Fig. 16. It shows a wing shaped ice accretion on the duplex conductor due to high torsional stiffness.

The lower loading on the duplex conductor is explained by the much higher rotational stiffness, which leads to the elongated icing shape (Fig. 16). Such a shape is more prone to ice shedding as laboratory tests have demonstrated [2] and it collects less icing than a single conductor that can rotate more freely [2], [6]. Results indicate that a single fixed load ratio between the simplex and duplex conductor does not exist for the whole loading range, i.e. the load ratio varies with the amount of icing.

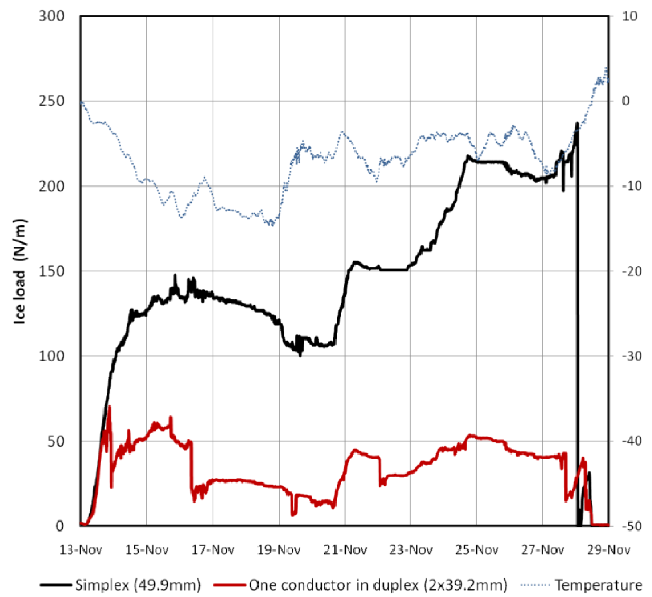

Fig. 14. Ice load on simplex conductor (49.9 mm) and one sub-conductor in a duplex conductor (2x39.2 mm) during the period 12-29 Nov.2006.

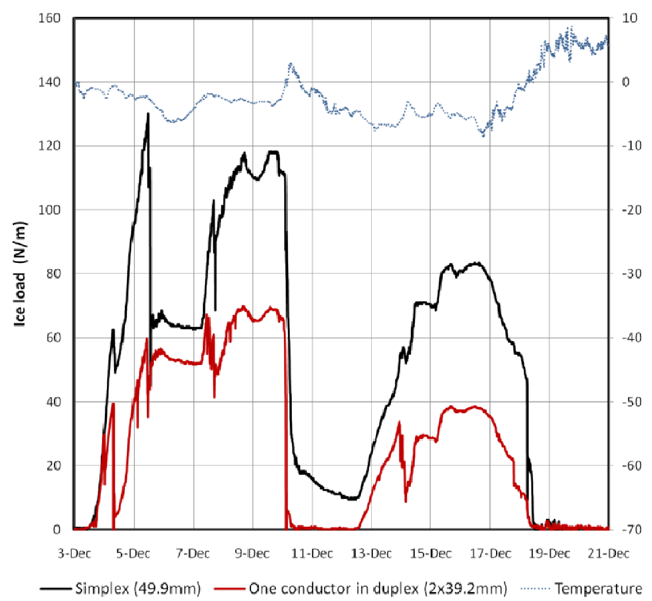

Fig. 15. Ice load on simplex conductor (49.9 mm) and one sub-conductor in a duplex conductor (2x39.2 mm) during the period 3-21 Dec. 2006.

Fig. 16. In-cloud icing on duplex conductor in FL4 (400 kV OHTL) in Dec. 2006.

B. Comparison of different conductors in test spans

Test spans A and C have been used to compare ice load on different conductor diameters and stranded versus smooth conductor.

A comparison of a stranded 28 mm AAAC conductor and a smooth 28 mm Aero-Z conductor was presented in [4]. The results indicated that there is generally a small difference in ice loading although ice shedding appears to occur a bit earlier with the smooth conductor.

A comparison of a 28 mm AAAC conductor and an 18 mm AAAC conductor was also presented in [4]. The results indicated that the accretion rate is similar. However, the extreme loading can vary greatly because ice shedding varies. The 28 mm conductor experienced more frequent ice shedding than the 18 mm conductor. Ice shedding had a significant impact on the extreme values and the highest measured values for the 18 mm conductor were greater by a factor of 2.

A comparison was made between test spans A and C during the period Sept. 2005 - Sept. 2007 by installing the same conductor (28 mm AAAC) in both spans. The purpose of the experiment was to see whether there is; (i) a systematic difference between the test spans, and (ii) a random effect of ice shedding which has a significant influence on maximum loading in icing events. The comparison of maximum ice load in each icing event is presented in Fig. 17. The results of 50 icing events generally show a good correlation between the test spans. There is one event where test span A experiences an extremely high loading (370 N/m) while test span C experiences considerably less loading (165 N/m). The loading curve for this event is shown in Fig. 18. It shows that the ice accretion rate is very similar up to 180 N/m, at a point where the ice falls completely of test span C, while it stays on test span A. Ice accumulation continues at both spans but at different rates due to different collection diameters. If ice shedding would not have taken place on test span C, it is reasonable to assume that maximum loading would have been very similar. This icing event shows how complicated it can be to interpret maximum possible ice loading, since random effect of ice shedding may be difficult to foresee. Fig. 19 shows another icing event where icing is very similar in both test spans. It was found reasonable to conclude that there is not a systematic difference between test span A and test span C. On the other hand, random effects of ice shedding were found to significantly influence maximum loading as Fig. 18 demonstrates.

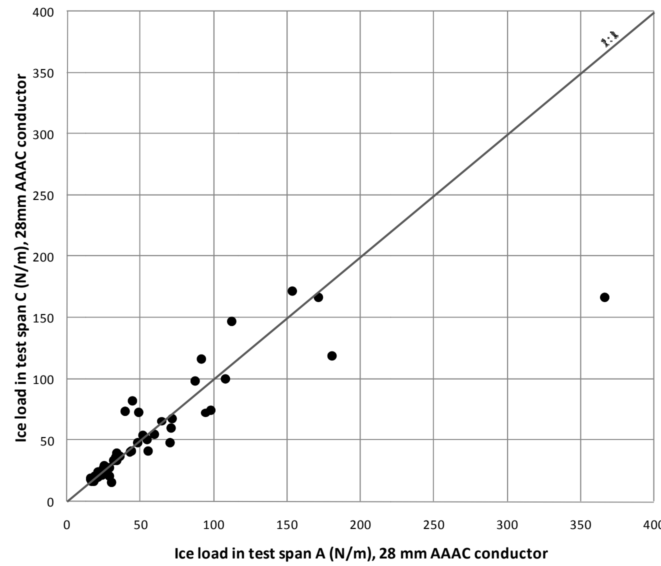

Fig. 17. Comparison between identical 28 mm AAAC conductors in test span A and test span C.

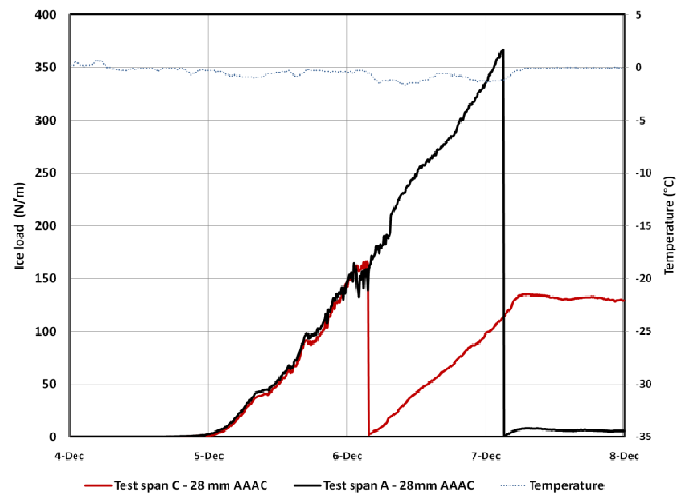

Fig. 18. Ice load in test spans A and C equipped with identical 28mm AAAC conductor in the period 4.-8. Dec.2000.

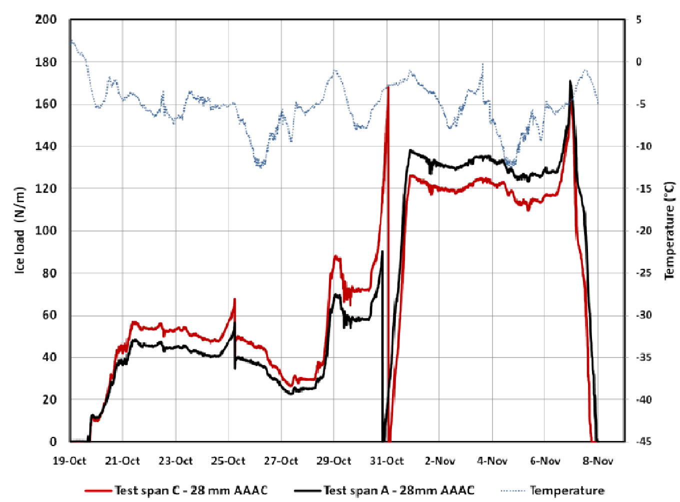

Fig. 19. Ice load in test spans A and C equipped with identical 28mm AAAC conductor during the period 19.Oct.-08 Nov.2005.

A comparison was made between a 28 mm AAAC conductor (test span A) and a 49.9 mm AACSR conductor (test span C) during the period Oct. 2007 to May. 2009. Results of 22 icing events are presented in Fig. 20 and examples of loading curves in three events are presented in Fig. 21 to Fig. 23.

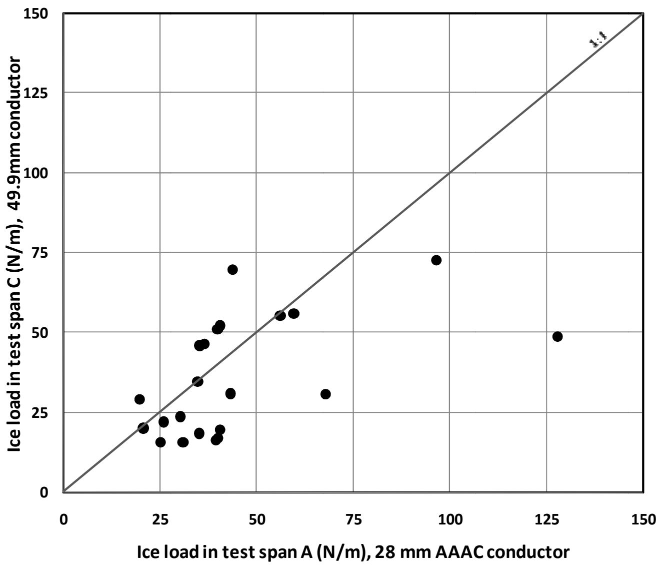

Fig. 20. Comparison between 28 mm AAAC conductor in test span A and 49.9 AACSR conductor in test span C.

The results show that the 28 mm conductor experiences more often a higher ice load than the 49.9 mm conductor, but there is considerable dispersion in values. The event with maximum loading on the 28 mm conductor is shown in Fig. 21. Substantial difference is observed between ice loads, where the 28 mm conductor is higher than the 49.9 mm conductor by a factor of 2.5. The difference is partly explained by ice shedding. Ice shedding also plays a role when the 49.9 mm conductor has higher loading in the event shown in Fig. 22. There is good coherence in accretion rate and maximum loading in Fig. 23. However, ice shedding first occurs for the 49.9 mm conductor and it could have lead to somewhat different maximum loading if ice accretion would have started again before ice shedding took place on the 28 mm conductor.

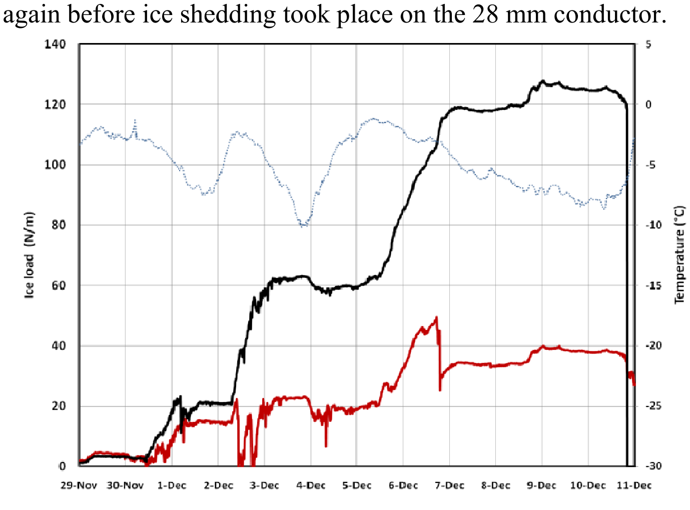

Fig. 21. Ice load in test span A with 28 mm AAAC conductor and test span C with 49.9 mm conductor during the period 29.Nov-11.Dec. 2007.

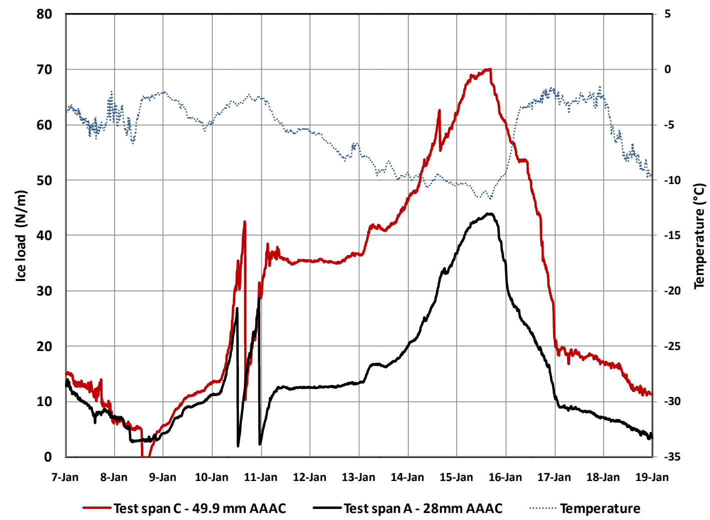

Fig. 22. Ice load in test span A with 28 mm AAAC conductor and test span C with 49.9 mm conductor during the period 7.-19.Jan. 2008.

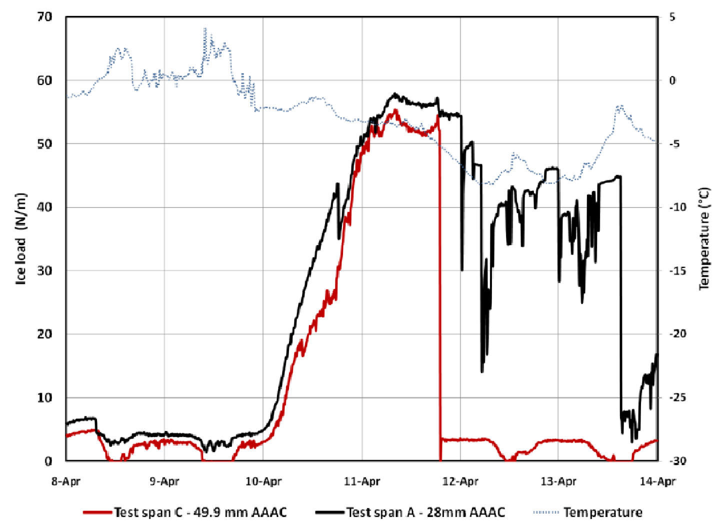

Fig. 23. Ice load in test span A with 28 mm AAAC conductor and test span C with 49.9 mm conductor during the period 9-14 Apr. 2009.

The comparison measurement using different conductor sizes in test span A and test span C shows that the smaller conductor size has a tendency to experience more extreme ice loading when loading is above ~70 N/m. Less frequent ice shedding on smaller diameters is thought to be the main reason since accretion rate is not markedly different. It should be noted that this conclusion is based on loading above approx. 50 N/m. Loading in the range of 20 to 50 N/m was not studied in this comparison and may give different results since it is less influenced by ice shedding and more influenced by different collection areas and collection efficiency. Fig. 24 presents all comparison measurements for conductor diameters of 18 mm, 28 mm and 49.9 mm in test span C and the 28 mm conductor in test span A. Measurements are fitted with power curves going through zero. The fit shows the tendency of smaller conductors to experience more extreme loading. It also shows that there is a considerable dispersion in values and the correlation is especially low for the 28 mm - 49.9 mm comparison.

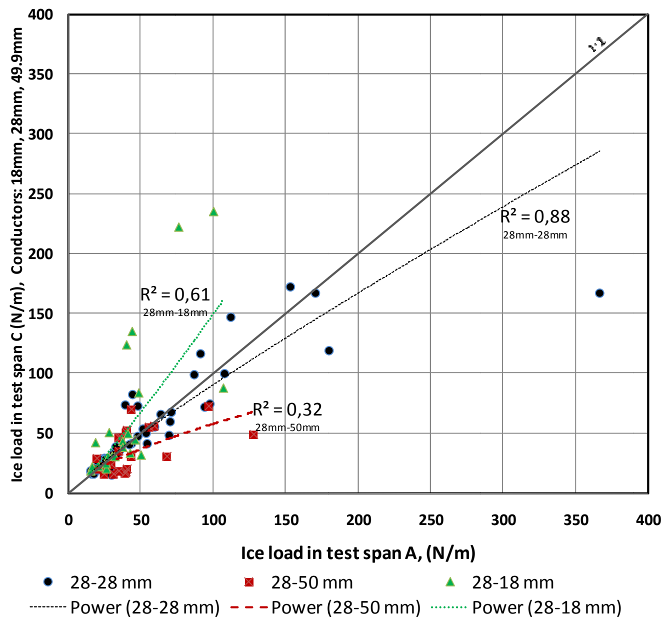

Fig. 24. Comparison of test span A (28 mm) to different diameter of conductors in test span C (18 mm, 28 mm, and 49.9 mm).

C. Comparison of test span and OHTL (49.9 mm conductor)

Many test lines are operated in Iceland in order to quantify extreme ice loading in different areas. The test spans are standardized in length of 80 m and 10 m in height. It is thus of considerable interest to compare ice measurements in test spans to OHTL. Test span C was installed with the same 49.9 mm conductor as FL3 (400 kV OHTL) during the period Nov. 2007 to May. 2009. A total of 18 icing events have been identified for comparison (Fig. 25).

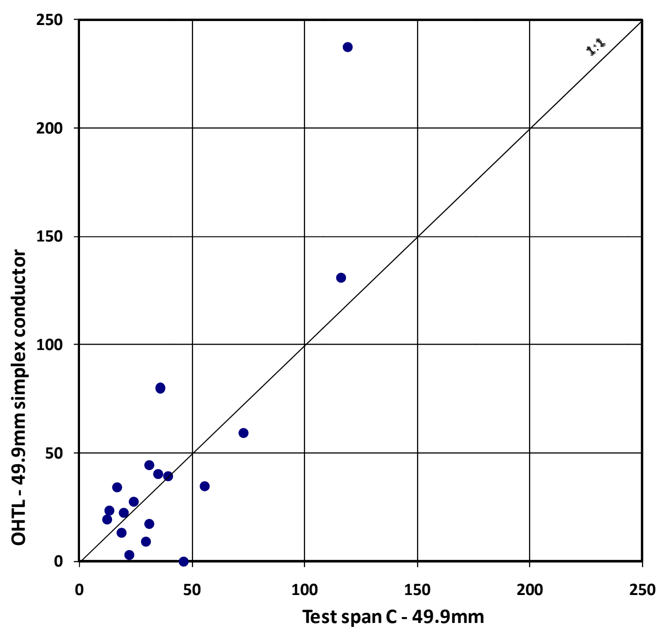

Fig. 25. Comparison between identical 49.9 mm AACSR conductors in FL3 (400 kV OHTL) and test span C.

The results show that there is a reasonably good correlation between the test span and the OHTL. The event with the most extreme loading (Fig. 26) is much higher in the OHTL due to ice shedding in the test span. The ice accretion rate is similar up to 130 N/m when shedding takes place in the test span. Ice shedding is also the reason why the OHTL has slightly higher value in the second highest icing event (Fig. 27).

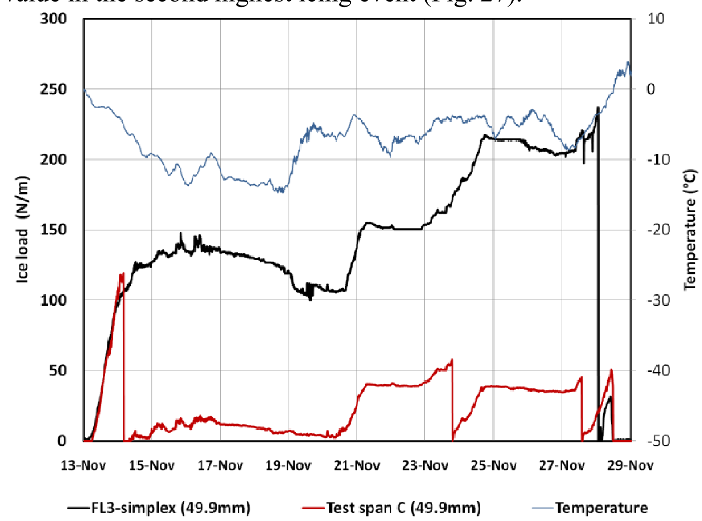

Fig. 26. Ice load with 49.9 mm AACSR conductor in FL3 (400 kV OHTL) and test span C during the period 13-29 Nov. 2006.

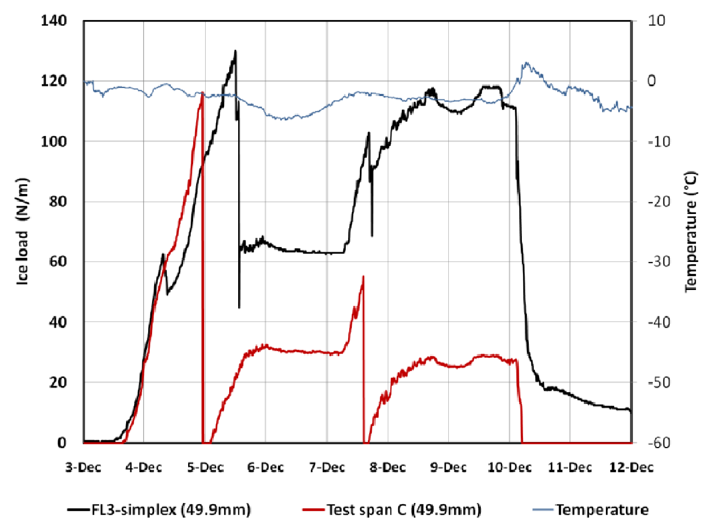

Fig. 27. Ice load with 49.9 mm AACSR conductor in FL3 (400 kV OHTL) and test span C during the period 3.-12. Dec. 2006.

V. Conclusion

The measuring site at Hallormsstadahals has frequent in-cloud icing events and is classified with icing severity between strong and heavy according to EUMENTNET/SWS II. Ice load measurements are obtained with five measuring units installed with different conductor setups. The measurements allow comparison between the different setups.

This paper mainly focuses on ice load measurement in the range of 50-350 N/m, which forms the basis for the comparison results. Comparison of loading below this range may lead to different conclusions.

Comparison was made on maximum ice load between simplex conductor (49.9 mm AACSR) in FL3-400 kV OHTL to duplex conductor (2x39.2mm AACSR) in parallel OHTL FL4-400 kV. Measurements show that the simplex conductor experiences in general higher ice load than each of the duplex sub-conductors. At lower loading, up to 50 N/m, it is only moderately higher, but in the two events with high loading >120 N/m (on the simplex) it becomes greater by factor of 2 to 4. It is not possible at the current stage to conclude if this difference of the high loading is typical or an exceptional case. However, the loading curves show that the difference is in line with the generally recognized knowledge that rotational stiffness of the conductor bundle plays an important role. The higher rotational stiffness of the duplex conductor leads to a more elongated ice shape that falls off before the semi-circular shape of the simplex conductor. The higher rotational stiffness also reduces the accretion rate above a certain load level. There are indications that the accretion rate slows down at around 70 N/m for each of the bundle sub-conductors.

A comparison was made on ice accretion for different sizes of stranded conductors. Measurements were obtained from two 80 m parallel test spans, A and C. Conductor diameters of 18 mm, 28 mm and 49.9 mm in test span C were compared to a 28 mm conductor in test span A. The results revealed a tendency of smaller conductors to experience higher loading. A definitive difference in accretion rate was not observed and the higher loading on the smaller conductors is primarily explained by more frequent ice shedding of bigger conductors.

A comparison was made on ice accretion on the same conductor (49.9 mm AACSR) between a transmission line installed with simplex conductor (FL3-400 kV) and a test span with 80 m long spans and attachment at 10 m in height. The results revealed reasonably good correlation. The most extreme loading, is though much higher for the OHTL due to ice shedding in the test span. The ice accretion rate is though similar up to 130 N/m. Ice shedding also explains why the OHTL experiences a slightly higher value in the second highest case.

When comparing maximum loading, it was found to be of major importance to view and consider accretion curves and ice shedding that takes place in maximum icing events. Both factors play an important role for the extreme ice loading and the influence of ice shedding should not be underestimated.

VI. References

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