Icing measurements, recent development in Iceland

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Abstract— **This paper describes recent development in icing measurements in Iceland. A brief description is presented of icing measurements in test spans that started in 1972. Initially, the motivations were plans for new overhead transmission lines over the highland with limited knowledge on icing risk. From 1972 till today, measurements in test spans have been performed at 61 locations. In many of them, loading is measured from different directions. Results from icing measurements have been used in line route selection, loading assumption and reliability assessment. Knowledge of icing risk has significantly improved in recent years, and today's usage for icing measurements has changed. Measuring devices and data transmission now allow cost-effective monitoring with load cells in insulator chains of operating transmission lines that also benefit the daily operation of the transmission system. A description is given of recent development and how the icing measurement network in Iceland is planned to be operated in the coming years.**

Keywords – ***Icing measurements, load cells, continuous recording, test spans, real-time monitoring.***

I. Introduction

Overhead lines in Iceland cover more than 130 years. Table I shows some milestones in icing research and construction of the overhead line systems in the country. The first theoretical study of icing on overhead lines was done by the Icelandic Engineering Society in 1953. A step forward was taken by the Transmission Line Committee in the years after 1972. In 1977 Árni Jón Elíasson became the supervisor of the work, first at the Icelandic State Electricity, in collaboration with other power companies. In 2005 Landsnet (The National Grid) was founded, and the company overtook all transmission lines in Iceland, 66 to 220 kV, and the icing-research project.

Fig. 1 Overhead lines in Iceland in 2019. The distribution OH line system covers most of the inhabited areas of the country.

TABLE I. Icing and overhead lines in Iceland, key milestones.

Year	Milestone
1890	The first overhead line (10 km telephone line) was constructed from Reykjavík to a nearby village
1906	The first major telephone line was constructed across the country from east to west (614 km)
1906	First major failure due to icing
1935	First transmission line, a 45 km long 66 kV line in the southwest
1946	The initiation of an 11 kV distribution net in rural areas
1953	First 132 kV transmission line
1953	First theoretical study on icing in Iceland
1969	First 220 kV overhead transmission line
1972	First test span built. Measurements performed with mechanical dynamometers
1972-1984	132 kV overhead transmission line system built around the country
1973-2004	The Transmission Line Committee sets the design ice-load for new overhead transmission lines
1974	Ice load assessed based on experience in Iceland
1977	Initiation of systematic collection of all known icing events on operating OHL
1988	First electronic load measuring device installed
1995	Systematic undergrounding of 11-33 kV lines begins
1996	First load cell installed in operating OHTL
2007	Start of on-line monitoring of icing
2007	First on-line camera/video installed in OHTL tower
2011	The first use of icing model and hindcast simulation to evaluate icing
2018	First measuring device powered by induction
2019-2022	Reorganization of the main measuring system for icing

At the initiative of the Icelandic government, a systematic recording of icing on existing overhead lines in Iceland started in 1976. The reason was the preparation of a system of 132 kV transmission lines around the country, and a reliable assessment of icing risk was needed. Before, transmission lines in Iceland (66-132 kV) had been designed with wind- and ice-load from foreign standards without considering weather conditions in Iceland.

In 1977, the largest distribution company, Iceland State Electricity (RARIK), overtook the project and set up a network of systematic registration at operating stations all around the country. Selected employees were trained for their role in registering icing events. In 2005 the project was transferred to Landsnet, the TSO of Iceland. Since then, the icing on transmission lines has been recorded continuously. Now many of the distribution lines have been replaced by underground cables.

The data from the systematic recording has been one of the bases for icing research in Iceland.

II. Measurements in test spans (1972-2019)

The first test span for the measurement of icing accumulation on wires was built in in October 1972. The year after (1973), four more were built. They were constructed using guyed wood poles with 80 m span, where an alloy-conductor with mechanic-dynamometer was used for measuring the stress and the highest load since the last time an observer was at the site. In the following years, more test spans were built, and in 1983 the total number was 36. There were three types, one span, two spans at a right angle, 90° and three spans, unilateral triangle, see Fig. 2. In 1982 the test spans were redesigned, all with the same type of conductor and guys, in accordance with ten years experience.

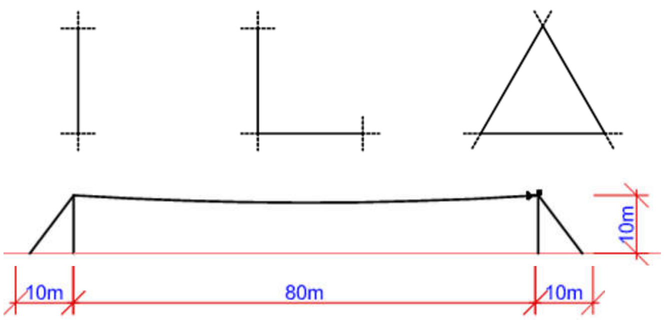

Fig. 2 Test sites with one, two or three test spans with different directions, Type I, Type L and Type Δ. Each measuring span is 80 m long.

In the first generation of test spans, the conductor goes over a wheel near the top to a dynamometer ca. 1.5 m above ground (Fig. 4). To improve the accuracy of the measurements, it was decided to skip the wheel and connect the measuring device between the conductor and the top of the pole (Fig. 5). This was done in the years 1996-2001. There have been built 91 test spans at 61 locations in Iceland. Fig. 3 shows the height of the measuring locations.

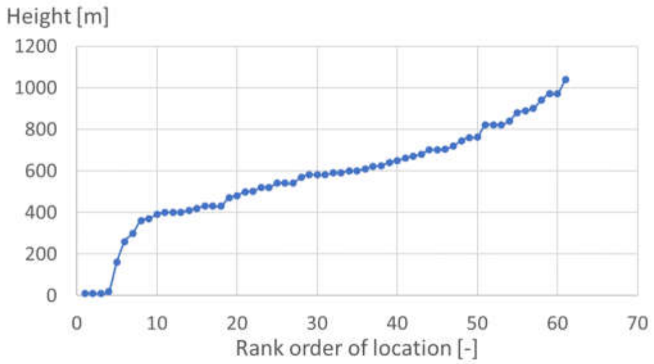

Fig. 3 Height of measuring sites above sea level.

In 1988 the first electronic (digital) measuring device with continuous measurements of ice load was tested and later improved. They were Icelandic design and product. Later versions were connected to the GSM telephone system with a real-time data transfer. The digital measurements were a significant improvement and gave interesting information on accretion, shedding, and galloping.

Since 1972 many test spans have been dismantled and the measuring device re-used in other spans. The longest continuous operation is in the test span 73-3 in the central highland, operated since 1973. At the end of 2019, there were 41 spans in operation (26 type I, 13 type L, and 2 type Δ).

Fig. 4 The first generation of test spans: The conductor goes over a wheel near the top and is connected to a mechanical dynamometer ca. 1,5 m above ground.

Fig. 5 The next generation: The conductor is connected at the top to a mechanical dynamometer (rectangular box) and a load cell with a digital recorder (circular box). A digital thermometer is on top of the pole, at the same height as the measuring wire.

Fig. 6 At some of the test spans Landsnet also operates weather stations, this one is in East-Iceland. Here it is covered in icing, and the anemometer is frozen.

References [1], [2], [3], [4] give further information on test spans and measuring data.

III. Measurements in operating OHTL (1996-2019)

In 1996 the first measuring device in an operating overhead line was mounted in a 132 kV line in the west. Six more were added in the years 2002-2006, two of them in eastern Iceland on Hallormsstaðaháls with, for the first time, a real-time transfer of data (2007), see [4]. The measurements in operating towers showed promising results, and it was decided to develop it further in connection with the planning of the test-span system.

The device is mounted above the insulator chain in a tower, and it measures the total weight (chain, conductor, ice- and wind-load). The test spans measure the tension in the conductor, and the weight of icing is calculated using information on the setup.

The measuring devices from the dismantled test spans are used at the new measuring sites in operating lines after being tested and repaired before installation.

A. The measuring device in old lines

The old digital tension recorders are used in suspension strings in older 132 kV lines, which are mainly of wood poles. A load cell with an amplifier is mounted above the insulator chain (Fig. 7). A cable from the device is fastened under the cross-arm to one of the poles and down the pole to a box with a logger, storing the data and transmitting electricity to the load cell. The box also contains a 4G telephone router and connections. Above is a 100 W solar panel, and below is a box with a 100 Ah battery (Fig. 8).

The load is measured every second and after 10 minutes, the maximum, minimum and mean value of the last 10 minutes are stored in the logger. The 4G router sends the results at intervals to a server in Landsnet's headquarters.

Fig. 7 The old digital tension recorders with built-in amplifiers are used in suspension strings in older 132 kV lines. A cable connects it to a data logger and a GSM sender at the base of the pole.

Fig. 8 A box with a GSM sender is mounted on the tower leg with a solar panel above, a battery below and a cable from the measuring device. A digital thermometer is above the box, ca. 2 m above ground. In the background is the old test span at the site, which will be replaced by the measuring site in the operating line.

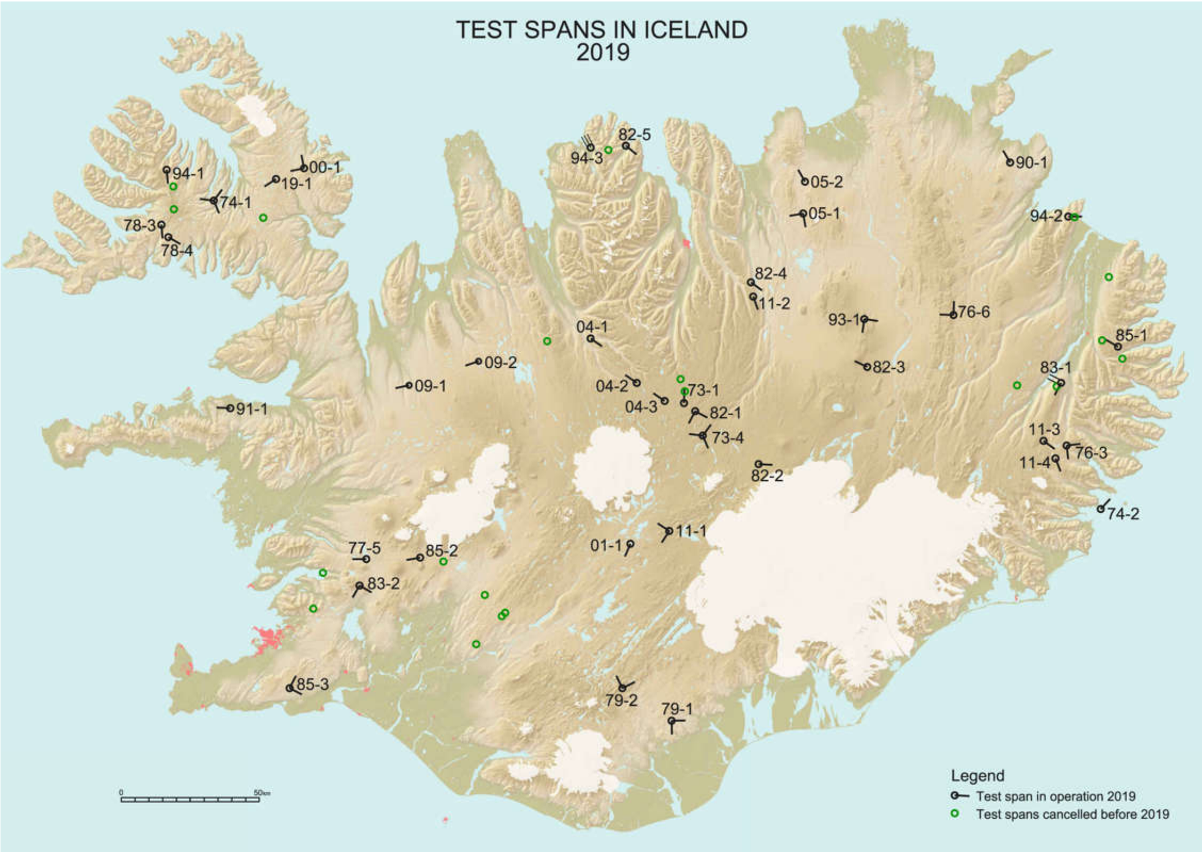

Fig. 9 Test spans in operation in December 2019 (41). The green dots show location of cancelled test-spans.

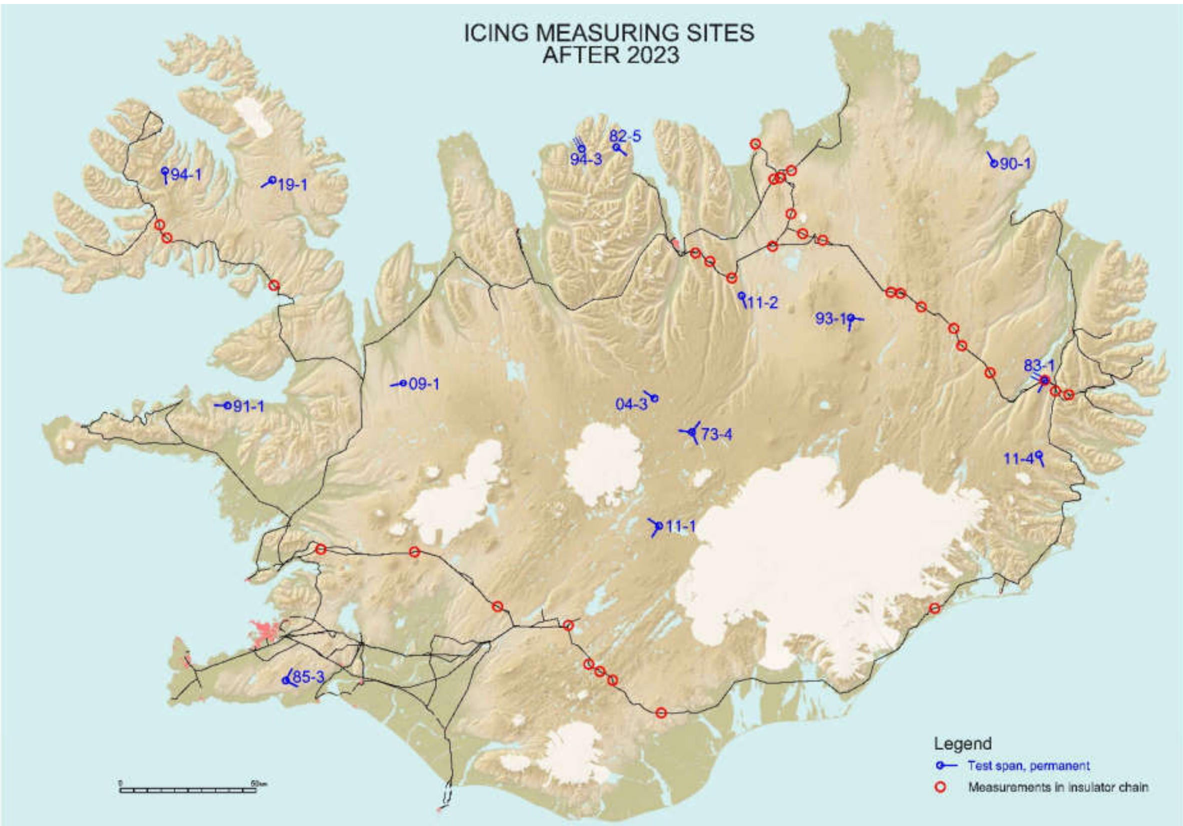

Fig. 10 Planned icing measuring sites after reorganization of the network in 2023. The blue sites show permanent test spans (15), the red dots show measuring sites in operating transmission lines, with load cells in insulator chains.

B. The measuring device in new lines

The new digital load-meters are installed in new 220 kV towers (Fig. 11). A load cell is mounted above the insulator chain (Fig. 12). A cable from the device is fastened under the cross-arm to an amplifier at one of the legs (Fig. 13), and from it down the leg to a box with a logger which stores the data and transmits energy to the load cell. The box also contains a 4G telephone router and connections. Above is a 100 W solar panel, and below is a box with a 100 Ah battery (Fig. 14).

The load is measured every second and after 10 minutes, the maximum, minimum and mean value of the last 10 minutes is stored. The 4G router sends the results at intervals to a server in Landsnet's headquarters.

Fig. 11 The measuring device is mounted in a new 220 kV tower.

Fig. 12 A load cell in an insulator string in a new 220 kV transmission line. A cable connects it to an amplifier and to a data logger and GSM sender at the base of the tower.

Fig. 13 A box with an amplifier is mounted below the cross-arm.

Fig. 14 The GSM sender is mounted on the tower leg with a solar panel above, a battery below and a cable from the amplifier.

The GSM-sender is the most power-consuming of the device. Limited sunshine is in the north of Iceland in midwinter time, and then a bigger solar panel and a stronger battery are necessary. At that time of the year, the data is sent at longer intervals to save energy.

Real-time monitoring using high-resolution cameras for image and video capture started in 2007. Initially, it required an expensive energy source, but recent development using electromagnetic energy harvesting technology as the power source has opened new opportunities. Three sites have recently been provided with cameras and instruments from Laki Power (Fig. 15). Preliminary results indicate that they give valuable real-time information for the day-to-day operation of the lines, such as timelapse videos verifying what is going on. Fig. 16 shows a photo from a camera installed on a conductor; it shows rime icing on one conductor in a duplex.

Fig. 15 Device from Laki Power installed on a conductor. Its power source is induced from the conductor.

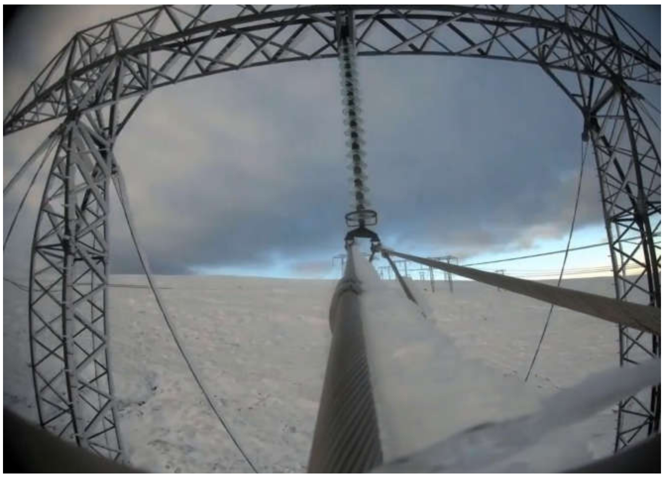

Fig. 16 Photo from a camera installed on a duplex conductor, showing minor rime icing. A device from Laki Power.

C. *The operation of the measuring sites*

Measurements in test spans: Generally, the staff visits the test span once a year to transfer data, replace batteries and inspect and repair the test span. Difficult places are sometimes visited at two years intervals, and then batteries and data storing memory must be more powerful. It is proposed that all the permanent test spans will have on-line connections within a few years and automatic weather stations on the same sites.

Measurements in operating lines: All measuring sites will be on-line connected to servers in Landsnet's headquarters, so the function can be checked on-line. It is expected that in most cases, it will be sufficient to inspect the device at a few years interval.

IV. The Reorganization of the Network (2019-2023)

The reorganization of the network includes that 26 test spans that were in operation in 2019 will be dismantled and partly replaced with measurements in operating lines. Several more such sites will be added (see Fig. 9 and Fig. 10).

The new measuring sites have been organized in three ways. a) In older lines, as a continuation of canceled test spans. b) In older lines, where high ice-load has been observed. c) In new transmission lines where high ice-load can be expected.

Landsnet is now building a new 220 kV line-system in the eastern and northern parts of Iceland. The measuring device is installed from the beginning of the operation, now at 10 locations (2022). The masts selected are usually located where the design ice-load is highest. It is expected that the real-time measurements and observations of ice accretion will increase the reliability of the transmission line system.

D. *One year overlap of old and new measurements*

In places where test spans are close to operating lines, the measuring sites will be transferred from the test span to a nearby mast in the line. But as the measuring setup is different and local conditions can affect the results because the sites are not exactly the same, both test span and insulator chain measurements will be conducted for one year simultaneously for comparison and evaluation of prior test-span results. An example from the Westfjords is shown in Fig. 17.

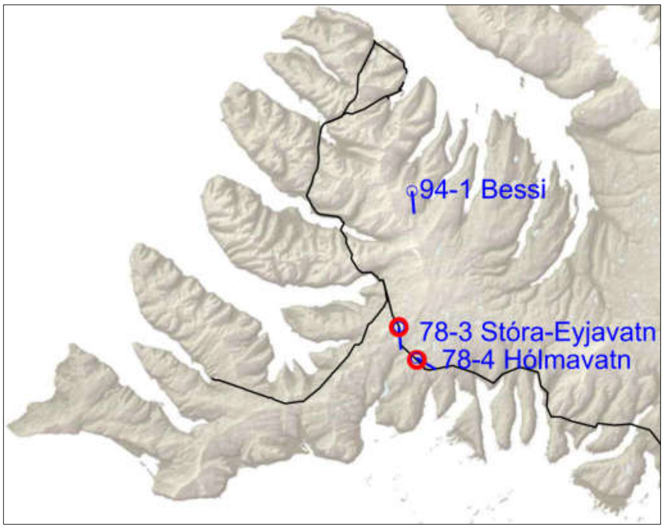

Fig. 17 In the Westfjords, two test spans are close to an operating 132 kV line. Red circles show nearby masts selected as measuring sites. Measurements continue for one year in both mast and test span. Test span Bessi is a permanent one.

E. *The role of the remaining test-spans*

After revising the icing measurement network, approximately 15 test spans will remain, see map, Fig. 10. Most of them are in places with no transmission lines. They are close to possible future line-routes and are of interest to define design ice-load for them and find out if the line-route is feasible. Two test spans have mainly meteorological interest.

The average ground altitude of these 15 permanent test spans is 492 m above sea level. The 41 test spans operating at the end of 2019 had an average altitude of 552 m, Fig. 3. Most of the icing episodes are in-cloud icing, although wet-snow icing can occur. Freezing rain is very rare in Iceland.

The average ground altitude for measuring sites in operating lines is 471 m.

The measuring sites will all be used to improve forecasting models for icing, covering both wet-snow-icing and in-cloud-icing throughout Iceland.

V. The Utilization of the Icing-Data

The original purpose of icing measurements in test spans was to substantiate the setting of design ice-load for new overhead transmission lines in challenging areas and get knowledge on ice-load for renovation and strengthening of old transmission lines. For the first 15 years, only the maximum loading from the last manual reading was collected. The continuous digital measurements were a significant improvement. The new system with measurements in operating transmission lines and permanent test spans will be another step forward.

The icing measurements have been used for the following purposes:

- To evaluate icing risk and operational reliability of new and existing OHTL
- To assess and improve line route selection for new overhead transmission lines concerning the risk of icing.
- To set the design ice-load for new overhead transmission lines, 132-400 kV. Ice load is determined for each line section of new lines.
- To prioritize the maintenance and strengthening of older transmission lines and revise the design ice-load.
- To prioritize underground cable projects in the case of old 11 kV distribution lines.
- To reform, verify and calibrate icing models that use meteorological models (e.g., WRF models) as input variables.
- To strengthen the possibilities for making more reliable short-term icing forecasts, which benefit the transmission system operators.
- The on-line measurements in the main transmission lines provide valuable information for the daily monitoring of the transmission system and planning of preventive measures.
- Information on in-cloud icing has been used in projects for other structures, such as new telephone and radio masts in exposed locations.

The results obtained from the test spans and measurements in operating lines have been presented in several papers, especially as IWAIS-Workshop-papers.

VI. Conclusions

Since 1972 a system of test spans has been in operation for icing measurements in Iceland. In the first years, they were equipped with mechanical dynamometers, but in the years after 1988, meters with load cells and continuous (digital) recording were developed. In 1996 the first load cell in an insulator chain in a transmission line was mounted, and in 2007, the first measuring site was equipped with an on-line transfer of data by a GSM sender. In the coming years, such measurements in operating lines are planned to be the primary ice-measuring method. Test spans will be used in some areas where no lines are available. This is especially important to support the development of the improvement of simulation models for icing. The measurements have provided valuable data to set ice- and wind-load criteria for new overhead lines. The data from the measuring equipment in operating lines are also useful for daily monitoring of the transmission line system, which will undoubtedly increase the operational reliability.

It is expected that a daily icing model forecast will be used as a part of the operation of transmission lines within a few years. The icing measurement system is an essential part of improving its accuracy and reliability.

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