Natural Hazards and The Icelandic Power Transmission Grid

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Abstract – *After basic changes in the legislation for the Icelandic power system in the beginning of the year 2005, one company Landsnet is now responsible for all the power transmission and system operation in the country. Design and management of the transmission system in Iceland must take into account that many kinds of natural hazards are always impending in this country of rough weather conditions and volcanic activity. This paper describes in a short overview the main natural hazards that can be expected and what reaction is made to minimize derived damage for Landsnet and its customers.*

I. INTRODUCTION

Iceland (103,000 square kilometres) is located at the rift zone of the North Atlantic Ridge. Active plate margins cross the island from southwest to northeast and an active hot spot underlies the central parts.

Fig. 1: Iceland is in crossroad of the Atlantic ridge and a route of low-pressure weather systems.

The areal extent of the volcanic and tectonic zones is about 30% of Iceland. It is one of the youngest landmasses of its size in the world,only 0 - 20 million years old. The oldest, non-active parts comprise the western- and easternmost part of the island. Some 11% of Iceland is glaciated (including 5 large ice caps) and so are many volcanoes.

The rifting due to the separation of crustal plates amounts to 2.0-2.5 cm pr. year on average. Local stress-build-up is periodically released and local rifting within the active zones may amount to many metres at a time. Earthquakes are frequent, both due to dilation of the crust and transverse motion. Volcanic activity is confined to about 30 volcanic systems. On the average, one eruption occurs every fourth year (during the last millennium).

Iceland is situated close to the polar weather front and in the path of major low-pressure systems that cross the North Atlantic.

Fig. 2: Low-pressure system approaching Iceland.

The action of powerful lows and frequent shifts in weather, in a temperature range from –10°C to +10°C, and rather high preciptitation in most parts of Iceland, cause numerous incidents of icing, high intensity winds, lightnings, meltwater floods, landslides and snow avalanches. Consequently, Iceland has to be defined as a country where natural disasters are common.

II. THE ICELANDIC POWER TRANSMISSION GRID

A new company Landsnet was founded January 1st 2005 on the basis of the Electricity Act, passed by the Icelandic parliament Althingi in the spring of 2003. The role of the company is to undertake the transmission of high voltage electricity and system management.

The company is not permitted to engage in any activities other than those which are necessary to be able to discharge its duties pursuant to the Electricity Act. However, the Company is permitted to operate an electricity market. The board of directors of Landsnet shall be independent of other companies engaging in the generation, distribution or sale of electricity.

All utilities and power intensive consumers in the country are connected to Landsnets´s transmission system which includes all transmission facilities of 66 kV and higher. Several transmission facilitities for 33 kV are also part of the transmission system of Landsnet. All power stations 7 MW or higher shall be connected directly to the transmission system.

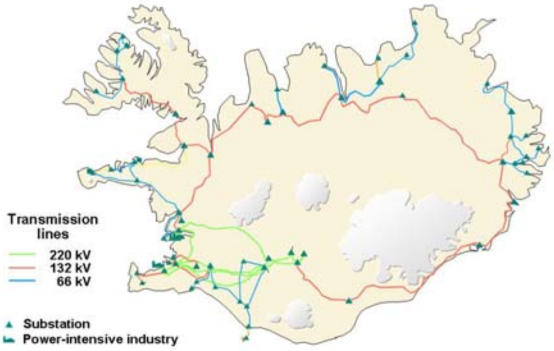


Fig. 3:The Landsnet’s Transmission System by 2005

The power grid consist of 66 substations, 56 points of delivery and approximately 3000 km of high-voltage transmission lines. Towers for 220-kV and 400-kV lines (still operated 220 kV) are nearly always made of steel (most of them guyed portal and V-towers) and are set on concrete foundations. Towers for lower voltage lines are in most cases made of wood. Followed by decision of construction of new aluminum factories, Landsnet is now building 230 km of 400 kV lines and necessary substations.

Electrical power potential is now estimated close to 50 TWh/year, thereof 60% hydro and 40% geothermal. Whereas utilisation is only 17 %, a lot of power is still unharnessed so extension of the net in the future is expected.

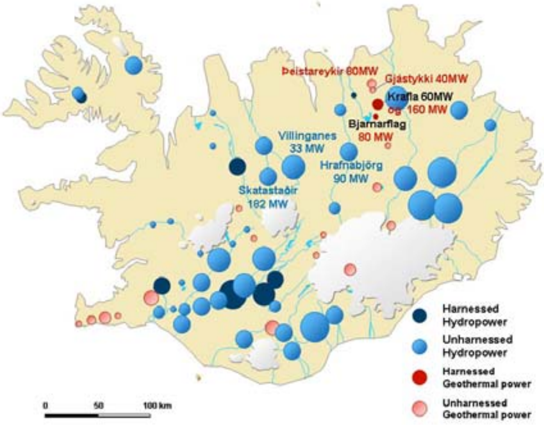


Fig. 4: Unharnessed power in Iceland.

III. NATURAL HAZARDS – EXPERIENCE AND DESIGN PRACTICE

Natural hazards in Iceland stem from different sources. Some hazards are more imminent than others. Volcanic eruptions are for example categorised as low-frequency hazards but icing a high-frequency hazard. A valuable experience already exists in tackling complicate events in nature.

Iceland has now implimented the EN 50341 standard (Cenelec) for transmission line design, but previously threre were rules similar to DIN-VDE 210.

A.Volcanic eruption

There were at least 34 volcanic eruptions recorded in Iceland in the 20th century. None were very violent but some did cause damage (especially in 1973, in the Heimaey island).

Fig. 5: Volcanic eruption in Heimaey island 1973.

In this case the sea cable from the mainland was damaged. The substation at the end of the cable was destroyed, also the headquarters of the local utility.

Very large lava eruptions occur a few times each millennium; the last being the Laki fissure eruption of 1783 with an almost 600 sq. km lava flow (12.5 cu. km). Large eruption spewing ash and tephra over large areas occur from time to time, like in 1362, 1755, and 1874. The tephra thickness may be up to many metres close to the volcano and can cover tens of thousands of square kilometres within a 0.5 cm isopach. Lightnings are common phenomena during submarine or subglacial eruptions.

The latter type of volcanic eruptions are rather frequent in Iceland as some mayor volcanic centres are glaciated. Such eruption produce tephra only as well as huge meltwater floods called “jökulhlaups”. The discharge varies from 10,000 to at least 300,000 cubic metres per second (three times the Amazon River) and the total water volume can be as much as 4-5 cubic kilometres. The flows carry a large amount of sand, tephra and icebergs over vast flood plains in front of glaciers or ice caps. The last “jökulhlaup” (from the Grímsvötn-volcano in the Vatnajökull Ice Cap, 1996) had a peak discharge of 48,000 cu. m/sec. In this flood 24 masts in the 132kV line passing all around Iceland collapsed.

Fig. 6: Consequence of “jökulhlaup”. Reconstruction of the line (132kV) has started between huge icebergs left by the flood.

The glaciated volcano Katla near the middle south coast is now estimated in a pre-eruption phase.

Influences of volcanic eruptions and derived events are difficult to avoid except by taking the risk into account when line routes are decided and substations are localised before construction.

B. Earthquakes

Thousands of earthquakes are registered every year in Iceland (M larger than 1.5). A few may attain M=4-5. Each century, however, a few earthquake series include quakes of M=6-7. The peak value to be expected is 7.0-7.5 (such events happened in 1896, 1912 and 1963). The seismic unrest is confined to volcanic systems and off–rift zones. The largest quakes are located in the off-rift zones, such as in the lowlands of South-Iceland and close to the northeastern coast. In 2000 two major earthquakes (M=6.4.-6.5) hit South Iceland and over 3,000 buildings were damaged but no serious injuries or fatalities occurred. Few transmission towers in the area were minor damaged by movement of foundations and bending of steeltowers units in bottom sections.

Further unrest can be expected in the area, maybe within the next few years. A monitoring and warning system has been built up in relation to volcano and earthquake hazards.

The main danger of earthquakes regarding transmission line towers are of landslides and movements of foundations. The landslides are avoided by placing towers in safe places. The movement of foundations are dangerous regarding self supporting towers. To make the foundations safe for self supporting towers the concrete foundations are connected by beams in earthquake areas to stabilise the base.

C. Avalanches and landslides

Gravity flows along slopes are frequent in Iceland. About 50% of Iceland attains elevation over 400 m a.s.l. Mountains and valleys are numerous and in many areas only a narrow strip of land separates mountains from the sea. Many valleys and pro-mountain landstrips are inhabited. This is evident in the fjord/valley-landscape of the northwest, central north and eastern part of the country. A dozen small and medium sized towns lie within or close to avalanche-prone areas (in winter) or landslide-prone areas (in the spring or summer). High winds and medium or high precipitation induce avalanche conditions whereas soils that freeze in winter thaw in the spring and may slip. Such events are registered up to hundreds of times each year. Most, however, do not harm lives or buildings but annually, a number of them cause damage to roads and powerlines have occasionally been hit by avalanches and in few cases by landslides.

In a 400 kV line under construction in eastern part of the country, 83 of 324 towers are especially designed to withstand severe avalanches in narrow valleys.

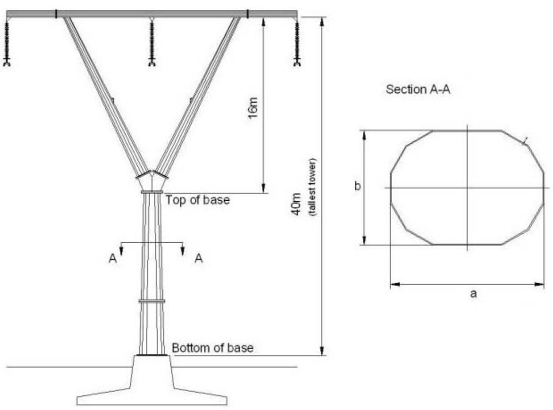


Fig. 7: 400 kV tower under construction, designed to withstand severe avalanches.

Towers are not specially designed in relation to landslides but an attemt is made to avoid it by taking the risk into account when the structures are localed before construction.

D. Lightnings

According to an Icelandic lightning location system and data from the ATD sferics system of the UK Meterological Office, lightnings can be expected everywhere in the country, but are most common in south and southeast [4]. The annual variation in thunder reports from manned observations during the fifty year period 1951-2000 shows two distinct thunder seasons, in the summer from mid June to mid August and in the winter from December to March.

Fig. 8: Tower in a 132 kV line, hit by lightning.

During summer there is a strong diurnal variation in the occurrence of thunderstorms, and data for 2000-2003 shows a significant increase in lightning activity in the afternoon. Recorded outages in the transmission grid the last 20 years are only approximately 70 so this is not a big problem, but the distribution utilities often beat with lightning problems in southern part of the country.

The advantage of shield wires for lightning protection in new transmission lines, more than 1-2 km from substations, is estimated in each case where risk of galloping and ice loading etc. is taken into account. As an example a single circuit 400 kV line (120 km) under construction is without shield wires because the risk of outages derived by galloping was estimated higher than by lightnings. Number of thunderstorm days in this area were only estimated one pr. year, but 1/5 of the line route passes areas known for galloping conditions.

E. Salt pollution

The main pollution problem in operating the transmission grid in Iceland is related to salt. There are three main sources of cases with high concentration of salt in the lower troposphere over Iceland. All of them are in connection with very low humitidy and therefore high rate of evaporation from sea. The first is when very dry air is blowing from west originating from the glacier of Greenland. The second when dry and very cold air from Labrador or Labrador sea is reaching Iceland from southwest and the wind is fastblowing for more than ca. 1 day (24 hours). The third case is when cold air is blowing for several days from north over Iceland and there will be mixing of airborne particles (salt) and dust from land in cases especially when the ground is not covered by snow late winter or in springtime. In cases when wet snow events follows, the power systems can get unstable.

For new lines the design criterion of minimum creepage distance is according to IEC Technical report from 1986, Publication 815. Generally category III “Heavy pollution level” is used with minimum creepage distance of 25 mm/kV. In exceptional cases, i.e. very close to seashore, category IV “Very Heavy pollution level” has been used.

Results of salt measurements seem to confirm that current design practice is in accordance with real circumstances.

F. Accumulation of snow

Occasionally localised accumulation of snow and snowdrift can cause overload on guyes and in some cases reach the conductors and cause outages.

Fig. 9: Severe accumulation of snow.

Such situation is obvisiously very dangerous because of traffic on snowmobiles. Problems derived by high accumulation of snow can be avoided by taking the risk into account when line routes are decided. A general design rule is to expect 20 cm of equally accumulated snow for each 100 m above sea level but never less than 40 cm. Effect of snowdrift is estimated for each area in tower spotting.

G. High intensity winds

Iceland is a somewhat windy country and storms are frequent. In the period 1912 – 2001, almost 940 severe storms hit Iceland (25 m/s at some 25% of weather stations at one time) or about a dozen times each year. Wind velocities for 10 min. intervals may attain values between 40-62,5 m/s, the highest figures recorded at elevations from 300-700 m a.s.l. The highest gust velocity measured in a weather station at high elevation is 74.2 m/s (267 km/h).

Fig. 10: Collapsed tower in a 220 kV line.

Storms cause material damage by sheer wind strength, by carrying precipitation with high salinity, sand particles or by inducing icing.

Wind velocities provided for in normal overhead line design are 52 – 60 m/s (50yr return period) at 10 m above ground based on 2-3 sec. wind gusts. Wind velocitiy is decided for each line section considering topographical effect. No provision is made for tornados, downburst or microburst types.

Conditions for conductors vibration are very common in Iceland. All transmission lines in the grid are equipped with dampers loops (bretelle) in all towers in 220 and 400 kV lines and in every second tower in 132 kV and lower.

H. Iceload

Iceland's location in the path of major low-pressure systems that cross the North Atlantic from north America to north Europe, makes appropriate condition for icing rather common in Iceland. The action of powerful lows and frequent shifts in weather, often create condition of temperature close to 0°C together with high precipitation and wind which very often lead to wet snow accumulation on overhead power lines.

Fig. 11: Wet snow icing on a conductor.

Wet snow load can be expected anywhere in the country, but is most common close to the shore in northern part of the country.

Transmission lines failures in Iceland normally occur in association with wind and ice. The wind velocity is often in the range of 25 - 40 m/s and ice diameter on conductors in the range of 7 – 15 cm. Major failure event occur approximately every 10 years. As an example 60 wooden masts were broken in 1987 in a 66 kV line. In 1991 600 poles were broken, most of them in the distribution net and 4 years later 500 poles were broken. Wet snow is the main icing problem. Freezing rain happens few times, but incloud icing is well known in the highlands where new transmission lines are planned.

Fig. 12: Incloud icing on a conductor.

Almost every year some damage is experienced on overhead lines, in most cases on distribution lines whereas the transmission grid is designed stronger. Last March (2005) 12 masts in a 132 kV line and 8 masts in a 66 kV line in east part of the country collapsed after a wet snow storm. Diameter of the ice was estimated 10 – 15 cm on conductors and weight pr. metre 5 – 14 kg. Wind speed could have been up to 40 m/s.

Iceload criteria for new transmission lines is decided for each line section and can differ a lot along the same line route, according to different topographical and weather conditions.

Galloping on conductors is well known, especially where incloud icing is common. Some dozens km of 132 and 220 kV lines have been installed with anti-galloping pendulums.

As in most countries in the world the temperature has been rather high in Iceland the last few years. As a consequence wet snow icing events seem to have been rather few this period in lowlands. At the same time incloud icing in the highlands seem to have increased.

IV. RESEARCH AND PRACTICAL USE

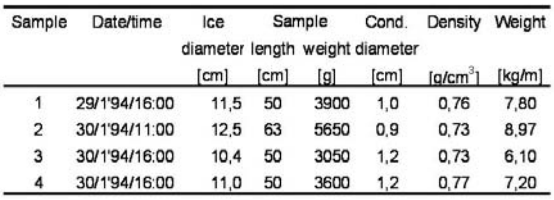
The key item in minimizing the damage derived by any kind of natural hazards is a comprehensive knowledge of the phenomena.

Extensive and practical knowledge is available in official research institutes, for example related to volcanic activity, earthquakes, lightnings and avalanches. On the other hand specilalised researches related to overhead lines have through the years been run by the transmission and distribution companies themselves.

Today Landsnet is running a program of investigation with main emphasis on ice- and windload on overhead transmission lines. The program is divided into few parts:

A. *Registration of icing events on overhead power lines*

The first transmission lines in Iceland were erected around 1940 but the main construction period was between 1955-1975. Individual reports on icing events exist from the beginning, but systematic registration of icing began in 1977. Since 1990 the registration applies to all overhead transmission and distribution lines in the country.



Sample	Date/time	Ice diameter [cm]	Sample length [cm]	Sample weight [g]	Cond. diameter [cm]	Density [g/cm^3]	Weight [kg/m]
1	29/1'94/16:00	11,5	50	3900	1,0	0,76	7,80
2	30/1'94/11:00	12,5	63	5650	0,9	0,73	8,97
3	30/1'94/16:00	10,4	50	3050	1,2	0,73	6,10
4	30/1'94/16:00	11,0	50	3600	1,2	0,77	7,20

Fig. 13: Field measurements and an example of a report.

To facilitate the access to existing information an icing database (IceDat) has been set up [1]. The database includes basic information on the icing and failures. For registration purpose an episode is defined as icing caused by the same weather system, which generally is caused by a low pressure system crossing the country from southwest to northeast. Thus a report of one episode can include icing events in many locations in the country at different times, usually within a day or two. The database contains information from more than 25 years continuous systematic acquisition of field icing data, in addition to random reports of icing events on structures, suchs as overhead telephone lines, even dating back to 1930. The database contains more than 3000 reports grouped in more than 500 icing episodes. Frequency of icing episodes on power lines is in correlation of increasing length of the grid through the period.

IceDat is now an indispensable tool for the power companies when evaluating line routes or deciding ice- and wind loads for new transmission lines. It has also been the main source of reference when determining the priority of underground cable projects in the distribution network [2].

B. *Operation of test spans*

Measurements of icing on test spans in Iceland have been ongoing since 1972. Today Landsnet operates a system of nearly 40 measuring sites distributed all around the country [3]. Each measuring site has one, two or three test spans lying in a straight line, at right angles or in a triangle. The spans are standardised, being 80 m long and strung on poles 10 m high. Conductor type is AAAC, in most cases 28.1 mm in diameter.

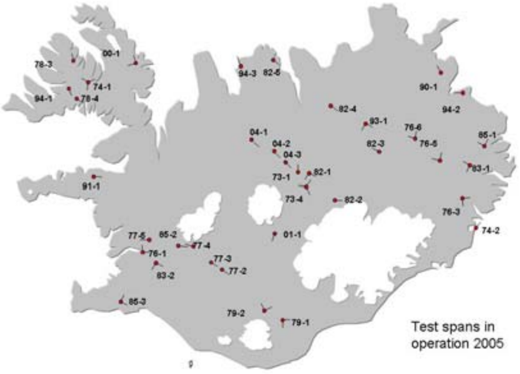


Fig. 14: Location of test spans.

The aim of measurements was originally to locate areas where high ice load can be expected. Most of the test spans are therefore located on planned or existing line routes and usually in the highlands at an altitude above 350 m. Measurements of the conductor's end tension are taken. The load analysed is the conductor's total load, consisting of both vertical and horizontal components.

Measurements on the test spans reflect diverse local circumstances related to icing. According to this average annual maximum loads for particular spans range from 1.5 to 25 kg/m. Highest measurement is 67 kg/m.

The last decade the spans have been instrumented with data loggers for load cells which have load ranges from 0 to 10 kN. They store three values, maximum, minimum and mean values, within each measurement interval, which usually is adjusted 10 minutes. Temperature is also measured at each site and in some instances more weather parameters are measured. More than half of the sites have been in operation for more than 20 years.

Analyses of the data from the tension recorders is ongoing and will give much more detailed information than before of timed accumulation icing episodes. This gives the opportunity to confirm weather condition at icing events and analyse ice shedding, galloping episodes etc.

Results of the test spans measurements have implemented load criteria used for overhead line design. When new overhead line routes are decided, informations of high wind- and iceload are taken into account.

C. Vibration measurements

Landsnet operates vibration measurements of conductors to confirm effectiveness of existing damping methods and to compare the effect of different dampers.

D. Lightning measuring system

Landsnet takes part in a lightning research program in Iceland by operating a lightning location system. Studies have been made to compare data from this system and atmospheric parameters from a numerical weather prediction model of Météo-France, Arpége. The results may enable the construction of probabilistic local thunderstorm forecast for Iceland [4].

E. Salt measurements

Salt accumulation on insulators is measured on few locations to improve electric design criteria and to improve warning methods for the grid’s operation [5].

F. Meteorological modeling

There are ongoing studies in Iceland on how local orography may create atmospheric conditions that are favourable for local wet snow icing [6 ,7].

An attempt is made to evaluate the impact of local orography and draw conclusions on the ability of numerical models to reproduce the icing conditions and to what extent they are sensitive to the resolution of the models.

The numerical model that has been used is the non-hydrostatic MM5 which is run with boundary values from the European Centre for Medium Range Weather Forecasts. Results so far indicate that mountains may favour wet snow icing upstream by increasing precipitation, creating a low level inversion and creating a barrier/corner wind.

Fig. 15: Wet snow iceload on a river crossing span.

Downstream, the mountains may favour wet snow icing also by increasing precipitation spill-over, by increasing wind speed – e.g. through gravity waves. The relative humidity is also reduced downstream and consequently, cooling by evaporation is increased.

High-resolution real-time simulations seem to be very likely to predict events of wet snow icing. High-resolution climate simulations nested into general circulation models may be helpful to locate areas of high risk of wet snow icing and possibly predict risk of wet snow icing in future climate.

G. International cooperation

Last but not least Iceland has been active in international cooperation inside IEC, IWAIS and CIGRÉ.

Finally it is worth to mention that in spite of all the different types of natural hazards listed up in this paper the Icelandic Transmisssion System´s reliability is fully competitve to similar systems in other countries, which has been confirmed by several international benschmarking studies during the last decade.

ACKNOWLEDGEMENTS

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