

Fall 2013

Investigating Risk Factors of Underground Power Cables in Iceland

Ingunn Gunnarsdottir

Furman University

The author extends special thanks to Guðleifur Kristmundsson, J. M. Garihan, M. Winiski, W. A. Ranson, Laura DeMarco and Gunnar Jónsson for invaluable guidance and assistance. Reykjavik Energy, Landsnet, Ingolfur Eyfells from Landsnet, S. Muthukrishnan, and Fanney Ósk Gísladóttir and Ólafur Arnalds (The Agricultural University of Iceland) supplied a much valuable information and data, making this research possible.

Recommended Citation

Gunnarsdottir, Ingunn, "Investigating Risk Factors of Underground Power Cables in Iceland" (2013). *Earth and Environmental Sciences Presentations*. Paper 4.

<http://scholarexchange.furman.edu/ees-presentations/4>

This Presentation (Class or campus) is made available online by Earth and Environmental Sciences, part of the Furman University Scholar Exchange (FUSE). It has been accepted for inclusion in Earth and Environmental Sciences Presentations by an authorized FUSE administrator. For terms of use, please refer to the [FUSE Institutional Repository Guidelines](#). For more information, please contact scholarexchange@furman.edu.

Abstract

In designing, installing and managing an underground electric power cable system in Iceland, efficient thermal dissipation in the soil surrounding the cable is critical in preventing thermal breakdown due to high temperatures at cable jackets. Two underground power cables extend from the Nesjavellir geothermal plant to Reykjavík. Previous work has shown that the thermal conductivity of soil is dependent on soil water content. There are various environmental factors that may affect soil water content, causing the soil to dry up. This study identified the various factors that should be considered when dealing with underground power cables, particularly with regard to Icelandic environmental conditions. Data on temperature and moisture around cables collected in the field at several sites, as well as a compilation of published meteorological information, and power production at Nesjavellir over a 90 day period, were used to determine relationships among these factors. A mineral analysis was performed on soil samples from sites, and the backfill material. Maps of the cable route, weighing different environmental factors that could possibly affect the soil water content were evaluated. These maps show the risk areas for cable failure to coincide with drier areas. There is a strong correlation between thermal conductivity and soil water content, supporting previous research. The backfill material surrounding the cable needs to have certain physical properties that allow for a consistent unrestricted thermal dissipation from the cable jacket. Due to environmental conditions in Iceland, the risk of cable failure is generally minimal. An exception is extended droughts in the summer, due to decreased soil moisture causing decreased thermal conductivity in the surrounding soil. The risk maps indicate that the area between the Nesjavellir power plant and Reykjavík is of relatively low risk. These results support the hypothesis that the soil surrounding an underground cable needs to have high enough water-holding properties for the thermal conductivity not to be affected by decreased soil moisture, thereby allowing for unrestricted thermal dissipation from the cable jacket.

Introduction

Recent research has shown that there are several different important factors to consider in the design and installation of underground cables. An understanding of soil physics has become critical in the design and installation of underground power transmission and distribution systems (Campbell and Bristow, 2007). Thermal conductivity of the surrounding material needs to allow for thermal dissipation from the cables. Restricted thermal dissipation can lead to high temperatures at the cable jacket, which will result in an increased risk of thermal breakdown of the underground cables and can reduce their lifespan considerably (Orradóttir and Sveinbjörnsson, 2009). Research has shown that the thermal conductivity of soil is impacted by the soil water content (Kristmundsson, 2007). Decreased soil water content leads to decreased thermal conductivity. Hence during droughts thermal conductivity is decreased in the soil surrounding the cables. Therefore it is important that the surrounding soil has sufficient water-holding properties so that the soil water content will not harmfully affect the thermal conductivity.

Knowledge of the various physical factors in Iceland which impact underground cables is vital in order to increase their efficiency and minimize failure risk in future underground cables. Currently, there are two underground cables that extend from geothermal power station, Nesjavellir, to substations near Reykjavík capital region, Nesjavalla-cable 1 and Nesjavalla-cable 2 (Fig. 1). Nesjavellir geothermal power station is located within the Hengill volcanic complex in southwest Iceland (Gunnarsson and others, 1992) (Fig. 2).

Furthermore, various factors need to be considered when selecting the location of an underground power cable system (Smits and others, 2009). Various properties of the area the cables extend through, such as the soil type, vegetation cover, elevation, and distance to water table, must be evaluated. It is reasonable to assume that higher and more stable moisture content in the surrounding soil would be beneficial.

The purpose of this paper is to identify the various factors that need to be considered when designing and installing an underground cable system. An analysis of the data collected around the younger Nesjavalla-cable 2 provides valuable information for this purpose. This research will further understanding of factors affecting underground power cables and their efficiency. It is critical to understand these factors in order to design better and more efficient underground cable systems.

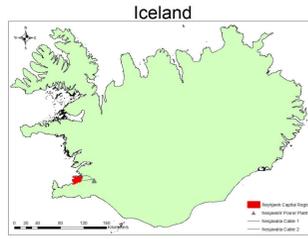


Figure 1: A map of Iceland showing the location of Nesjavellir geothermal power plant, Reykjavík capital region, and the placement of Nesjavalla-cables 1 and 2.



Figure 2: Nesjavellir geothermal power plant located within the Hengill volcanic complex (photograph from Grettar Ivarsson, 2006).

Study Area

At Nesjavellir, Reykjavík Energy operates a geothermal power plant with 120 MWe of installed capacity and a 200 MWt plant for hot water used in space heating (Eyfells, 2010). There are two high voltage underground cables that extend from Nesjavellir power plant, Nesjavalla-cable 1 and Nesjavalla-cable 2 (Fig. 1). These two cables ensure electrical transmission from Nesjavellir to the capital area. Generally, the cables are located in a trench at about 90 cm depth in the center of a 70 cm thick layer of thermally conductive backfill material (Fig. 3). The backfill material was thermally conductive and highly compacted sand chosen for its favorable thermal properties (Landsnet, 2011). Both Nesjavalla-cables are 132 kV high-voltage cables consisting of three XLPE cables with aluminum conductors that are placed in a trefoil. When constructing Nesjavalla-cable 2, it was necessary in some areas to place the cable in thermally conductive FTB-concrete (Fluidized Thermal Backfill) because of unsuitable environmental conditions, such as steep slopes. Additionally, through mountainous area, the cables were placed in holes drilled through the foothills. In these drill holes, the cables were covered with thermally conductive geothermal grout material.

The Nesjavellir power plant is located within the Hengill geothermal area, in southwest Iceland. The Hengill geothermal area is one of the largest high-temperature areas in Iceland and is located on the plate boundary between North America and the European crustal plates (Fig. 4). These two plates are diverging at a relative rate of 2 cm/year in east-west, opening a north-northeast trending system of normal faults and frequent magma intrusions. Fault movement along the Mid-Atlantic Ridge is the main cause for thousands of micro-earthquakes each year in the study area (Gunnlaugsson and Gislason, 2005). Even though earthquakes are common within the area, they are rarely of a higher magnitude than 5 on the Richter scale (Landsnet 2014). However, destructive earthquake sequences are known to occur at intervals of 45 to 112 years consisting of earthquakes with magnitudes over 6.5 (Geirsson, 2003).

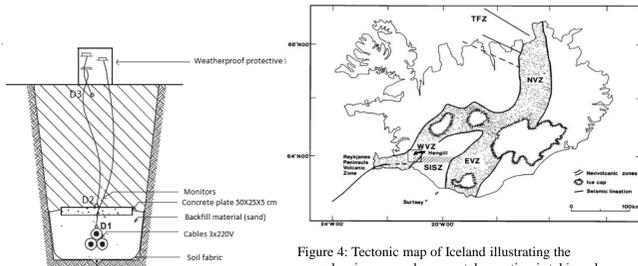


Figure 4: Tectonic map of Iceland illustrating the neovolcanic zones where crustal accretion is taking place, and the transform zones. The Hengill geothermal and volcanic area is indicated by a box within the Western Volcanic Zone (WVZ). Other acronyms on the map are: TFZ, Tjornes Fracture Zone; NVZ, Northern Volcanic Zone; EVZ, Eastern Volcanic Zone; SISZ, South Iceland Seismic Zone. (Miller and Foulger, 1998, Figure 1)

Methodology

Field Methods

A cross section schematic of the underground cables, showing the placement of monitoring devices, is given in Figure 3. My field measurements consisted of recording soil temperature, soil water content, and cable temperature at different positions and distances from the cable at two locations along Nesjavalla-cable 2. In addition, I collected the amount of power production from the geothermal power station at Nesjavellir. Hourly weather data from the Icelandic Meteorological Office in Reykjavík also was collected.

Laboratory Methods

For mineral identification, I used a regular binocular microscope and a petrographic polarizing microscope on surface soil samples from the two measurements sites and a sample of the backfill material used for Nesjavalla-cable 2. Crushed fragments at thin sections of materials were done and examined.

Analytical Methods

The data collected between May and August 2013 were used to monitor and observe the effects of weather and varying power production on the cables. In order to analyze the data further, I compiled all collected data in an Excel file. I used these data to create several graphs in order to determine any trends or correlations among the various factors. In addition, I produced numerous maps between Nesjavellir geothermal power plant and Reykjavík, using GIS mapping software. The purpose of these maps was to evaluate the different environmental factors that might affect the underground cable system. To do this I mapped the potential risk areas of cable failure based on the various environmental variables. I weighted the different variables, concluding that soil type, land cover, and elevation are the most important ones and produced a risk map based on each one of these factors. In order to determine the higher risk areas based on all the different variables, I layered a raster of each one of the maps together, thereby producing a conclusive risk map.

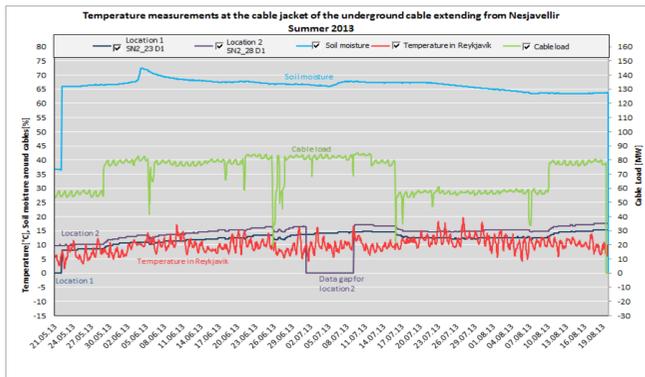


Figure 5: Compilation of data of different variables. Graph shows temperature measurements from summer 2013 at the cable jacket of Nesjavalla-cable 2, extending from Nesjavellir geothermal power station to Reykjavík, capital region. Additionally, it shows temperature in Reykjavík, and the cable load from the power plant. Horizontal axis is dates and vertical axis is temperature (°C), moisture (%), and cable load (MW). Measurement location 1 is denoted as SN2_23_D1, and measurement location 2 as SN2_28_D1. Temperature data for location 2 (SN2_28_D1) was not collected between July 1st and July 9th, (in data gap on diagram).

Sample	Surface soil at measurement locality 1	Surface soil at measurement locality 2	Backfill material
Minerals Present	Pyroxene Olivine Plagioclase Magnetite	Pyroxene Olivine Plagioclase Magnetite	Olivine Pyroxene Plagioclase Magnetite Altered pyroxene Basaltic rock fragments
Texture	High contents of fine sand, silt, and organic material		Crystals of various sizes
Other comments	Abundant fine roots		

Table I: Mineral analyses of surface soil samples from measurement sites, and a sample of the backfill material used.

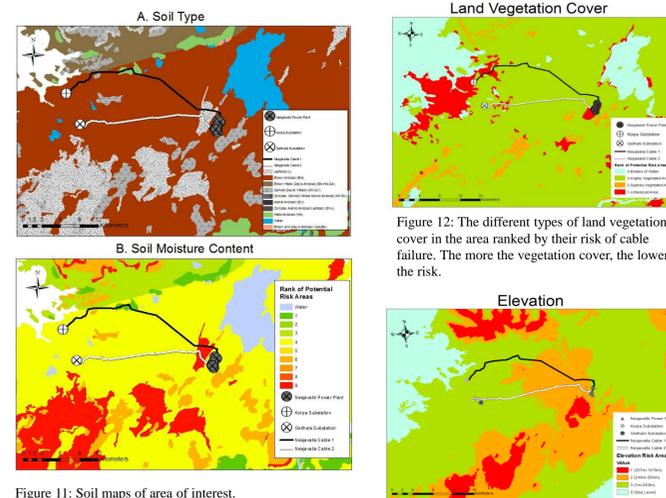


Figure 11: Soil maps of area of interest. A: The different types of soil in the area of interest. B: The potential risk of cable failure, where red represents high risk areas, and green low risk areas. This ranking is based on soil moisture content where the lower moisture content, the higher the risk of cable failure.

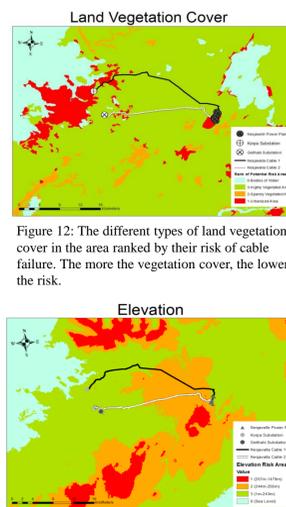


Figure 12: The different types of land vegetation cover in the area ranked by the type of cable failure. The more the vegetation cover, the lower the risk.

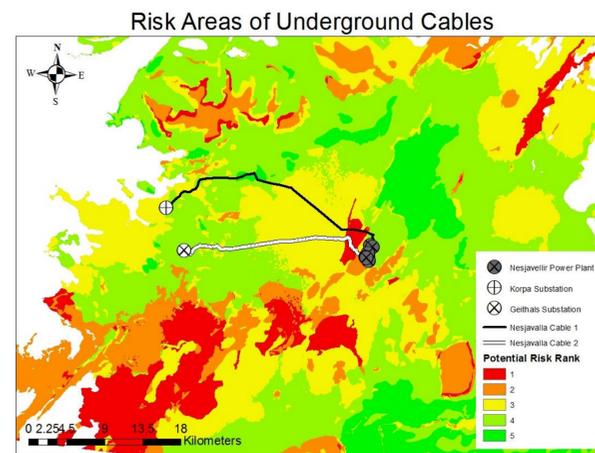


Figure 13: Elevation in the area of interest broken into four categories, based on natural breaks in the elevation data. The higher the elevation, the higher the risk.

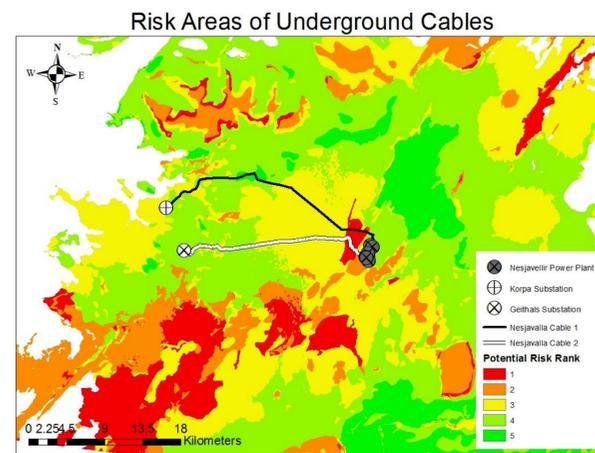


Figure 14: Overlay of the soil type, land vegetation cover, and elevation risk maps (Figures 11, 12, and 13). All the variables overlapping provide a composite risk map for the area of interest. Based on previous research, the risk based on soil type (i.e., the soil moisture) was weighted the heaviest.

Results

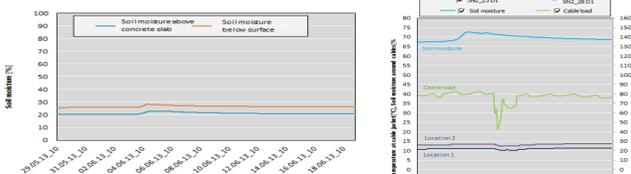


Figure 6: Graph indicates that soil moisture progressively decreases further into the soil, in closer proximity to the cable.

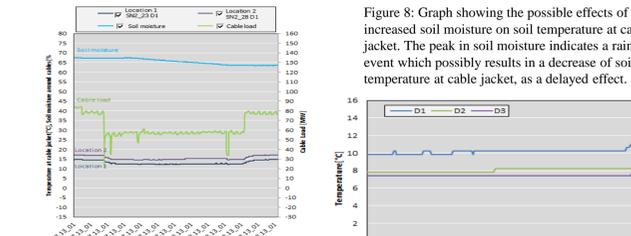


Figure 7: Graph showing the effects of decreased cable load on soil temperature at cable jacket. A reduction in cable load results in an immediate decrease in soil temperature at cable jacket.

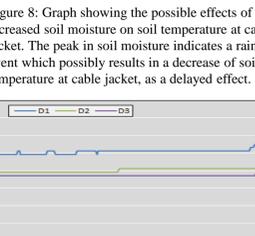


Figure 8: Graph showing the possible effects of increased soil moisture on soil temperature at cable jacket. The peak in soil moisture indicates a rain event which possibly results in a decrease of soil temperature at cable jacket, as a delayed effect.

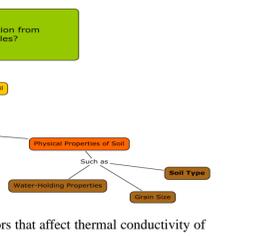


Figure 9: Graph showing soil temperature measured at three different positions and distances from the cable (Fig. 3). Soil temperatures progressively increase in closer proximity to the cable.

Field Data

Measurements around Nesjavalla-cable 2 are compiled in Figure 5. This diagram plots soil moisture (%), and soil temperature at the cable jacket (°C) measured at two locations on the Nesjavalla-cable 2. Additionally, the graph shows temperature in Reykjavík (°C), and cable load (MW). On the diagram the horizontal axis shows dates, and vertical axis is temperature (°C), moisture (%), and cable load (MW). Graphs of data show some easily discernible trends. A graph showing soil moisture measured at two different positions within the soil indicates that soil moisture progressively decreases further into the soil, in closer proximity to the cable (Fig. 6). A reduction in cable load results in an immediate decrease in soil temperature at cable jacket (Fig. 7). The soil moisture is increased after rain events (Fig. 8). An increase in soil moisture generally results in a slight decrease of temperature at cable jacket, as seen around June 4th-5th following a major rain event. A further analysis of temperature data shows that soil temperature progressively increases as distance from cable decreases (Fig. 9).

Laboratory Data

The results of mineral analysis are given in Table I.

Analytical Data

According to previous studies, a reduction in soil water content leads to a reduction of thermal conductivity in the soil. Therefore it is possible to conclude that the main risk areas of underground cables are those areas that are drier or are more prone to becoming dry. Using the GIS mapping software, it is possible to map the area where the Nesjavalla-cables extend to locate risk areas for cables. There are various environmental factors that can affect the soil water content, as seen in concept map (Fig. 10). I concluded that soil type, land vegetation cover, and elevation would be the main variables affecting the soil moisture; most importantly was the soil type. Along with Laura DeMarco, I produced a risk map for these variables, with the objective that drier areas are higher risk areas.

Soil type risk map (Fig. 11): Each soil type ranked based on their moisture content, as determined by the soil's water-holding properties (among other factors). An evaluation of this map shows a high risk area close to Nesjavellir geothermal power plant. **Land vegetation cover map** (Fig. 12): Assumed that a more densely vegetated area would have inherently more consistent soil water content, and therefore be a lower risk area. There appears to be a high risk area close to Nesjavellir power plant on the map. **Elevation risk map** (Fig. 13): Assumed that higher elevations would have lower soil water content and therefore be a higher risk area. The risk map shows that the area, elevation wise, is relatively low risk.

Composite risk map (Fig. 14): Layered the three risk maps together weighing the soil type risk map the heaviest therefore the resultant risk map is quite similar to the soil type risk map. The area from Nesjavellir to Reykjavík seems to be relatively low risk, apart from the high risk area close to Nesjavellir power plant where the cables, in anticipation of problems, extend as either overhead lines or underground cables surrounded by thermally conductive concrete. An analysis of the surrounding area shows that the present cables are located in the lowest risk area for cable routes. The area southwest of Nesjavellir does not have favorable conditions for underground cables; high risk areas there are caused by unfavorable soil type and high elevations (above 1450 m).

Conclusion

In this research, an analysis of the risk factors of underground power cables in Iceland is presented, based on field, laboratory and analytical data, and a review of the published research. The main problem with current underground cable designs in Iceland is that restricted thermal dissipation in the soil surrounding underground cables can lead to high temperatures at the cable jacket, resulting in an increased risk of thermal breakdown. The main cause of inefficient thermal dissipation is reduced thermal conductivity in the surrounding the cables. There are several factors that can impact the thermal conductivity of soil. Most important is soil water content, whereby decreased soil water content results in decreased thermal conduction. This study showed the importance of certain physical properties of soil in order to maximize thermal conductivity. Thermally conductive material has high water-holding properties, low organic content, heterogeneous aggregate size, and is highly compacted. The factors listed all affect the thermal conductivity of soil, and therefore it is essential that the backfill material surrounding underground cables has these properties. Additionally, high temperatures at cable jacket can be prevented by reducing the cable load. My research has demonstrated that published research on underground cables is also relevant for the research sites I studied.

An understanding of soil physics is critical in the design and installation of underground power transmission and distribution systems. Other professionals, such as electrical power engineers, can use this research to aid them in designing better underground cable systems in the future. The goal is a decreased risk of thermal breakdown and an extended lifespan of the cables. Furthermore, the risk map generated in this research, provides a tool for the selection of where to place any future cables from Nesjavellir power plant. Any future cables should probably extend through the same area as the current cables do.

Acknowledgements

The author extends special thanks to Guðleifur Kristmundsson, J. M. Garrihan, M. Winiski, W. A. Ranson, Laura DeMarco and Gunnar Jónsson for invaluable guidance and assistance. Reykjavík Energy, Landsnet, Ingolfur Eyfells from Landsnet, S. Muthukrishnan, and Fanney Ósk Gísladóttir and Ólafur Arnalds (The Agricultural University of Iceland) supplied a much valuable information and data, making this research possible.

References

Campbell, G. S., and Bristow, K. L., 2007. Underground Power Cable Installations: Soil Thermal Resistivity: Application note for Decagon Devices, p. 1 - 4.
Geirsson, Halldor, 2003. The June 2000 earthquake sequence in South Iceland: Installation. Implementation report on the task execution, NEZ-01; Landsnet, p. 1 - 24.
Landsnet, 2014. Impacts of Earth Quakes on Underground Power Cables, p. 1-20.
Miller, A. D., Julian, B. R., and Foulger, G. R., 1998. Three-dimensional seismic structure and moment tensors of non-double-couple earthquakes at the Hengill-Grensdalur volcanic complex, Iceland: Geophysical Journal international, v. 133, p. 309 - 325.
Orradóttir, B., and Sveinbjörnsson, E., 2009. Thermal dissipation from underground power cables: The impact of droughts on the Nesjavellir power cable: Journal of the Agricultural University of Iceland, n. 20, p. 1 - 16.
Smits, K. M., Sakaki, T., Linssuwa, A., and Illangasekare, T. H., 2009. Determination of the thermal conductivity of sands under varying moisture, drainage/wetting, and porosity conditions- applications in near-surface soil moisture distribution analysis: AGU Hydrology Days 2009, p. 57 - 65.
Ivarsson, Grettar, 2006. Nesjavellir Power Plant: http://en.wikipedia.org/wiki/File:NesjavellirPowerPlant_edti2.jpg (photograph retrieved August 2013) http://en.wikipedia.org/wiki/File:NesjavellirPowerPlant_edti2.jpg.
Kristmundsson, G. M., and Kristmundsson, Á., 2004. Thermal conductivity of soil around the underground cable from Nesjavellir: Annual book of VFI/TFI 2004, p. 245 - 251.
Kristmundsson, G. M., 2007. Thermal conductivity of soil and heat formation at the cable jacket of the high-voltage underground power cable from Nesjavellir geothermal power station: Annual book of VFI/TFI 2007, p. 61 - 64.
Landsnet, 2011. Nesjavellir - Geithóls: 132 kV underground power cable: earthwork and installation. Implementation report on the task execution, NEZ-01; Landsnet, p. 1 - 24.
Landsnet, 2014. Impacts of Earth Quakes on Underground Power Cables, p. 1-20.
Gunnarsson, A., Steingrímsson, B. S., Gunnlaugsson, E., Magnússon, J., and Maack, R., 1992. Nesjavellir Geothermal co-generation power plant: Geothermics, v. 21, n. 4, p. 559 - 583.
Gunnlaugsson, E., and Gislason, G., 2005. Preparation for a New Power Plant in the Hengill Geothermal Area, Iceland: Reykjavík Energy for World Geothermal Congress 2005, p. 1 - 6.
Ivarsson, Grettar, 2006. Nesjavellir Power Plant: http://en.wikipedia.org/wiki/File:NesjavellirPowerPlant_edti2.jpg (photograph retrieved August 2013) http://en.wikipedia.org/wiki/File:NesjavellirPowerPlant_edti2.jpg.
Kristmundsson, G. M., and Kristmundsson, Á., 2004. Thermal conductivity of soil around the underground cable from Nesjavellir: Annual book of VFI/TFI 2004, p. 245 - 251.
Kristmundsson, G. M., 2007. Thermal conductivity of soil and heat formation at the cable jacket of the high-voltage underground power cable from Nesjavellir geothermal power station: Annual book of VFI/TFI 2007, p. 61 - 64.
Landsnet, 2011. Nesjavellir - Geithóls: 132 kV underground power cable: earthwork and installation. Implementation report on the task execution, NEZ-01; Landsnet, p. 1 - 24.
Landsnet, 2014. Impacts of Earth Quakes on Underground Power Cables, p. 1-20.
Gunnarsson, A., Steingrímsson, B. S., Gunnlaugsson, E., Magnússon, J., and Maack, R., 1992. Nesjavellir Geothermal co-generation power plant: Geothermics, v. 21, n. 4, p. 559 - 583.
Gunnlaugsson, E., and Gislason, G., 2005. Preparation for a New Power Plant in the Hengill Geothermal Area, Iceland: Reykjavík Energy for World Geothermal Congress 2005, p. 1 - 6.
Ivarsson, Grettar, 2006. Nesjavellir Power Plant: http://en.wikipedia.org/wiki/File:NesjavellirPowerPlant_edti2.jpg (photograph retrieved August 2013) http://en.wikipedia.org/wiki/File:NesjavellirPowerPlant_edti2.jpg.
Kristmundsson, G. M., and Kristmundsson, Á., 2004. Thermal conductivity of soil around the underground cable from Nesjavellir: Annual book of VFI/TFI 2004, p. 245 - 251.
Kristmundsson, G. M., 2007. Thermal conductivity of soil and heat formation at the cable jacket of the high-voltage underground power cable from Nesjavellir geothermal power station: Annual book of VFI/TFI 2007, p. 61 - 64.