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Comparison of High Voltage Cables with Existing Overhead Lines to Increase Energy Security in the Westfjords of Iceland

Prepared by:

Ali Naderian, PhD, PEng, SM IEEE

Babak Jamali, MSc, PEng

Thor Hjartarson. MSc. PEng

Glen Winn, PEng

METSCO Energy Solutions

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1. Executive Summary

This report provides options for rebuilding and hardening the present 132 kV and 66 kV transmission systems in the Westfjords of Iceland. This report also gives consideration to hardening and converting some parts of the 33 kV system to 66kV in Westfjords to increase energy security in that area. A general comparison of the overhead and underground systems is also provided.

Two options have been considered for increasing energy security in Westfjords. One option is to underground segments, or all of the overhead transmission lines. This may sound extreme, however, Denmark decided in 2009[2] to underground their entire 132kV and 150kV transmission systems to improve energy security. Following that decision, and due to growth in the renewable offshore energy industry, many other countries are starting to increase the amount of underground cabling in 132kV, 230kV, 345kV, and 400kV systems. Westfjords experienced considerable transmission systems damage and extensive outages in the winter of 2013-2014 as a result of ice loading on the overhead lines. It is proposed that by replacing 132kV and 66kV overhead lines with underground cables in that area, outages would decrease more than ten-fold. Although overhead power lines are typically more economical, they are exposed to the elements and susceptible to damage from debris, high winds, and ice-loading conditions from extreme weather. Also, overhead lines in same area often fail at same time causing large disturbances as they are prone to extreme weather events.

Another option that has been discussed is the construction of a new hydro plant. The energy security risk is, however, mostly attributed to the overhead exposure so a new plant will not solve the problem.

The main benefits of underground cables include superior reliability, lower line losses, lower operating costs and being essentially immune to storms, volcanic ash, salt contamination, icing, less of an environmental footprint, and generally preferred by the public. The main benefits of overhead lines are that they are less expensive and simpler to construct, easier to trouble-shoot and repair, and generally have less thermal loading constraints providing more capacity for a given cable size.

Table 1 below shows a Total Cost (includes purchasing cost, Installation cost and cost of losses (over a 40 year period)) for three scenarios; status quo or Do Nothing, conversion of MJ1 to underground, and conversion of BD1, TA1, BV1, and IF1 to underground. Installation cost (earthworks, cable laying and finishing) for underground cable is about three times more than the material cost. This is a large part of the investment cost and it can vary significantly between projects, depending on site conditions and project requirements.

Table 1: Comparison of Costs and Reliability

Cost and Reliability estimation	Approximate circuit length (km)	Total Cost (M€)	Reliability (failure rate) per 100km/year
Doing Nothing		**Social cost per year** **3.26** [1]	**14** [1]
Replacing existing 132 kV overhead line (MJ1) with 132kV cables	**81**	**69.22**	**0.28** [2]
Replacing existing 66kV overhead lines (BD1 + TA1 +BV1+IF1)- with 66KV cables	BD1 = 36.4 TA1 = 45.1 BV1= 17.1 IF1= 14.7 **Total length = 113**	**92.12**	**0.15** [3]

During long outages, there are a number of potentially life-threatening risks and other impacts for customers such as despair, discomfort, anxiety and helplessness. These social costs mentioned in reference 1, are estimated at 3.26 M€.

TA1 is the longest 66kV overhead line section; approximately 45km. MJ1 is 81 km long and requires more attention to control the overvoltages and resonance. Each underground cable circuit is unique so that in each case, system design modelling needs to be done to confirm practicality and ensure compatibility with the network. Also, there is always the option of having a blend of overhead lines and underground cables, utilizing underground cables for sections most exposed to overhead risks.

Other advantages of underground cable options generally include fewer safety risks, less EMF exposure, elimination of corona discharge, and less environmentally intrusive. It can be in the public interest for utilities to be accommodated on road right-of-ways when such use and occupancy do not adversely affect safety, construction, maintenance or operations. Often underground cables can be installed beside roads to minimize land disruption and allow easier access. This could be an option for the new 66kV and 132 kV underground circuits.

A significant consideration when selecting an underground cable option is the initial investment cost including material and construction. Additionally, underground designs require special technical attention to overvoltage, resonance, and reactive power compensation. These are all technical issues that have been studied and can be solved.

The useful life of modern underground cable is at least 60 years provided good installation and workmanship practices are followed and cable loading is properly managed. Overhead line construction is generally less sensitive to these concerns, however, their exposure to the elements can increase inspection and maintenance costs, and in the extreme, may require major premature rebuild.

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2. Introduction

This report provides options for rebuilding and hardening the present 132 kV and 66 kV transmission systems in the Westfjords of Iceland. This report also gives consideration to hardening and converting some parts of the 33 kV system to 66kV in Westfjords to increase energy security in that area. A general comparison of the overhead and underground systems is also provided.

In 2009, the Minister of Industry in Iceland assigned a consulting group to assess ways to improve energy security in the Westfjords of Iceland and the report was delivered in February 2011. A survey conducted by the consulting group revealed that about 50% of responding companies believed they were directly impacted and suffered losses due to the interruption of production and damage to equipment. *The social cost of unsafe energy supplies has been estimated at about 400 million króna per year.* [1]

There are differing opinions in Iceland for increasing the energy security for the Westfjords. One opinion is that the construction of the Hvalá power plant can provided improved energy security by connection from Hvalá to the transmission system. However, this author believes the proposal will have relatively small effect on security of energy supply in the Westfjords because the major supply risks are associated with the exposure of the overhead supply. The Report [1] described that in the winter of 2013-2014, longer duration faults occurred on the transmission systems as a result of ice loading on the lines. A more direct approach to improving reliability is the mitigate the overhead exposure by converting overhead to underground cables. By replacing overhead lines with underground cables, outages due to storms and icing will be reduced significantly in the range of one order of magnitude (ten-fold).

Innovation in underground cable and accessories technology has contributed to an increase in underground transmission networks projects in the last few decades. Other factors driving decisions to underground solutions is more frequent, and more severe weather events leading to catastrophic overhead failures and the protracted, and extremely costly repairs. As people and communities recover from lengthy outages, utility companies, politicians and social groups start questioning the design philosophy and returns of investment of electric system infrastructure. Frank Alonso and Carolyn Greenwell, engineers at Science Applications International Corporation (SAIC) write in the aftermath of hurricane Sandy in the United States, *"Although overhead power lines are typically more economical, they are susceptible to damage from wind-borne tree branches, debris and high wind and ice-loading conditions from extreme weather. The damages can cause extended power outages that in extreme cases cannot be restored for days or even weeks, as we have seen after Hurricane Sandy. The cost for repairing the physical damages can be in the billions of dollars. During long outages after a catastrophe, there are also associated intangible impacts to a utility's customers such as despair, discomfort, anxiety and helplessness."* [4] Iceland has its own history with similar extreme events including 1991, 1995 and 2012. The event in 1991 resulted in over 550 distribution poles being destroyed with severe outages for customers whereas the event in 2012 had over 100 distribution poles destroyed and according to RARIK (Iceland State Electricity) that event would have been much more catastrophic if not for approximately half of their distribution lines having been replaced with underground cable in the last 20 years.

3. Power Transmission System in the Westfjords of Iceland

The electricity transmission system in the Westfjords consists of one 132 kV line and five 66 kV lines owned by Landsnet, and one 66 kV line as well as 33 kV lines owned by Orkubú Vestfjarda (OV).

Landsnet has two 66 kV lines from Mjólká. They are Tálknafjarðarlína and Breiðadalslína. From Breiðadal there are 66 kV lines to Bolungarvík and Ísafjörður and 66 kV underground cable between Ísafjörður and Bolungarvík. Out of five 33 kV power lines, three of them connect Mjólká and Breiðadal with a connection to Hrafnseyri and Þingeyri. A 33 kV line runs from Geiradal to Hólmavík and from Keldeyri to Bíldudalur.

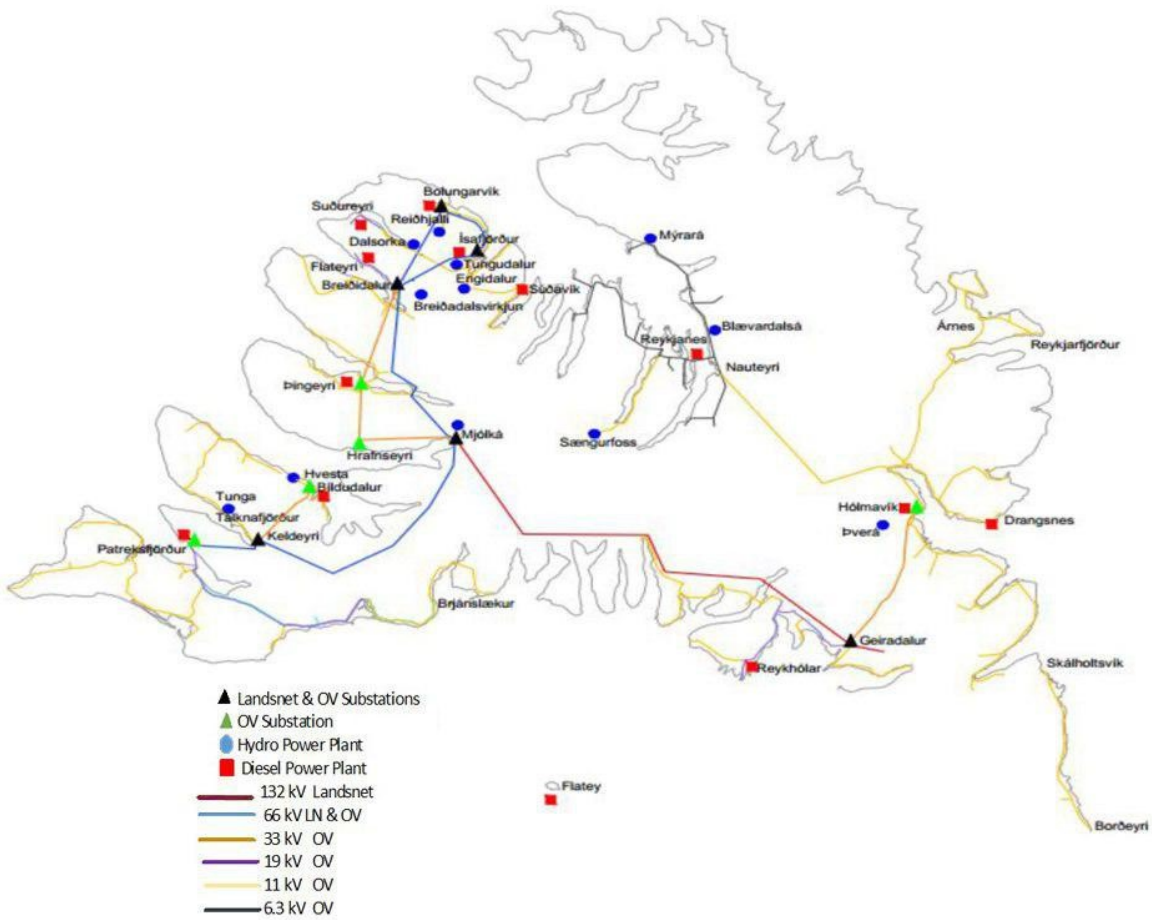

Figure 1 : Transmission Network, Westfjord Area of Iceland

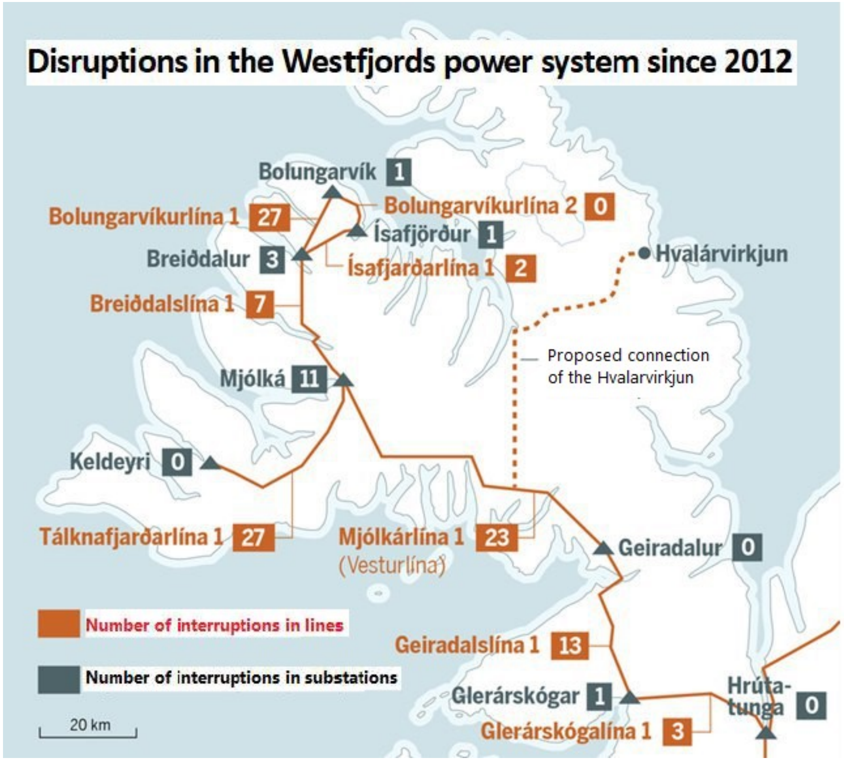

Figure 2: Disruptions in Westfjord power system since 2012 [16]

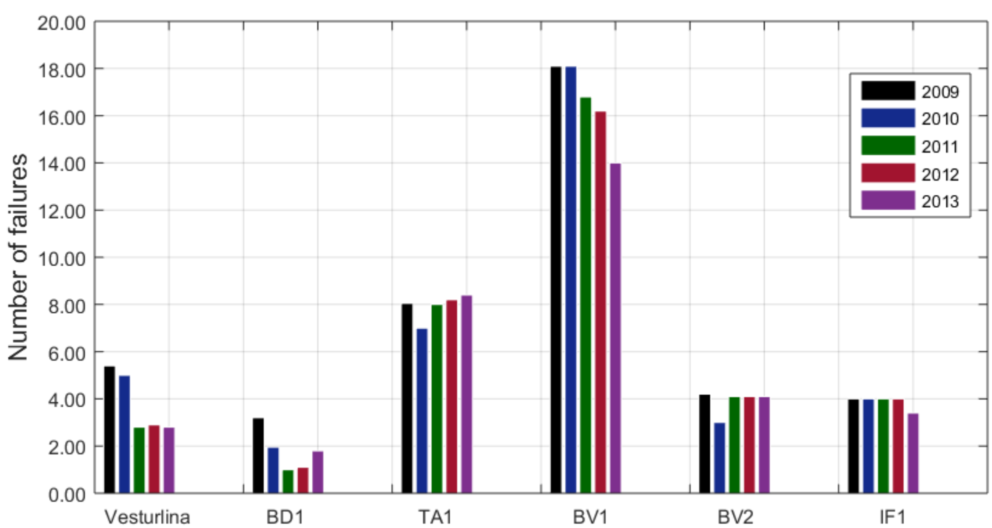

Figure 3: Annual number of failures on transmission lines/(100km) in the Westfjords

Figure 3 shows the annual number of faults between 2009 and 2013 for both 132kV and 66kV transmission lines in the Westfjords

Three 132 KV lines, Geiradalslína 1 , Mjólkárlína 1 and Glerárskógarlína 1 are called Vesturlina .

One suggestion is to consider replacement of the 132 kV Mjólkárlína 1 (MJ1)overhead line with 132kV underground cable and also replace the 66 kV Tálknafjardar Line 1 (TA1), Bolungarvíkur Line 1 (BV1) , Breiðadal Line 1 (BD1) and Isafjordur Line 1(IF1) with underground cables.

Upgrading the 33kV system (from Mjolka to Hrafnseyri , Þingeyri and Breidadalur) to a 66 kV system could also be considered, through a 66kV ring connection. These suggestion will need a deeper feasibility study.

Due to the overload of the transformer in Mjólká, Landsnet has decided to increase the capacity of the substations. The load demand of the Westfjords has increased steadily in recent years, and it expects to exceed 40 MW within 20 years. Current power transformer capacity in Mjólká is 30 MVA and it is clear that additional capacity with be required in the area.

In order to increase the power supply in Mjólká, two possibilities were considered. [1]

1- The possibility of replacing the existing power transformer with a larger unit. That advantage is that the existing transformer would be stored as a reserve.
2- The alternative is to purchase another similar large power transformer and associated switching equipment to install next to the existing transformer to create a double circuit.

It was decided to choose the first option; purchase a new 50 MVA power transformer. Landsnet's estimated cost for the project is around 2.2 million Euro [1].

4. Use of Underground Cables Worldwide

Over the last decades, power transmission networks across the globe have been developed based on the use of overhead transmission lines (OHTL). Transmission underground cables systems have been available for many years, but their use has been limited by large capacitance and dielectric losses as well as a relatively low power rating compared to OHTL for similar cross-sections.

In more recent years, the use of underground and submarine cables for power transmission has increased considerably. This is partly due to improved technology with new materials and a larger and more stable cable manufacturing market. However, facing a large increase in power demands and difficulties in installing new OHTL in Europe, it has become essential to consider the use of longer underground cable segments. This is demonstrated by the increasing numbers of long AC cable projects that have been carried out in many countries during the past 20 years.

The demand to connect renewable energy sources to the grid and supply power to major infrastructure in remote locations, has been increasing. In most countries the process of getting environmental approvals to build an OHTL can take as many as 7 - 8 years, whereas the process of getting approval for installation of underground cables in public areas may only take 1-2 years. The net result is that an AC cable link may be built in 2-3 years compared with 8 -10 years for an OHTL. This alone can be the reason to justify the AC cable link as it provides a much quicker return on the investment.

In Denmark, power generation has changed significantly due to its location as a transit country of energy between central Europe and the hydro power of Northern Europe, as well as the large increase in offshore wind farms and local renewable energy production. In 2007 the Energy and Transport Minister established the Electricity Infrastructure Committee in order to make a technical report for the future reinforcements of the Danish transmission network [2].

In 2009, based on the Committee's conclusions, the Danish government took the first step worldwide towards a cable-based transmission system. Due to the strategic location of the Danish grid, being a transit country between central and northern Europe, the strength of the Danish grid network, and the fundamental change of the Danish power system with increased scattered wind power, it was possible to exchange the existing OHTL system with underground cables. There was a choice between six different solutions, ranging from undergrounding the entire transmission system on 132-400 kV, to doing no grid expansion.

After performing an independent analysis of these six possibilities, the Danish government, with the involvement of all stakeholders, chose a solution called option C with an estimated cost of 2.3 billion Euro. New power lines on 400 kV will be underground, while existing towers can be refurbished and new towers and overhead lines are to be chosen for an existing line route. Visual appearance of the existing 400 kV network will be improved with new tower design and partial undergrounding on specifically chosen sections. The entire existing 132 kV and 150 kV grids are to be undergrounded in Denmark [2].

Following this decision, and due to the increase in the renewable offshore energy industry, many other countries are starting to increase their amount of underground cables in 132kV, 230kV, 345kV, and 400kV lines.

5. Overhead versus Underground Lines

Some of the critical technical requirements for the planning and design of building or upgrading an existing transmission line to either OHTL or underground transmission line (UGTL), are determined by several factors [Peter Nefzger, Ulf Kaintzyk, Joao Felix Nolasco, 2003] [5] as follows:

- Terminal Substations and line length
- Power to be transmitted in normal and emergency conditions
- Type of transmission; AC vs. DC
- Conductors, voltage, necessity of shield wires
- Number of circuits
- Tower type, phase configuration
- Use of earth wires such as optimal ground wires
- Maximum allowable losses
- Maximum acceptable levels of electrical and magnetic fields

Beyond just electrical and system characteristics, there are also other factors such as terrain, environmental and governmental policy constraints. From a construction perspective, the land has to be secured as right-of-way (ROW) in both cases of OHTL and UGTL. Overhead lines are traditionally attached to insulators mounted on transmission structures which vary in height and design based on the voltage level and phase separation required between the conductors. The OHTL ROW typically spans 45m-85m for 132 kV to 220 kV whereas the UGTL ROW is typically 12-14m.

Figure 4: Underground Transmission Cable and Overhead Conductor [6]

The overhead line structure is preassembled and shipped to the construction location and placed on prefabricated buried steel tubes or concrete foundations. No additional digging is required on each site as the transmission line is built. Clearances need to be met when crossing roads, structures and water bodies such as lakes or rivers. Maintenance of overhead lines is typically simple as they are easily accessible in open spaces. As overhead lines are exposed to dirt, moisture and lightning strikes, short circuits due to flash-overs or overvoltage surges do happen. These are typically transient faults and line condition can be restored with delayed reclosing after allowing the fault to clear. Line ratings are altered based on ambient temperature, loading, wind, sunlight etc. In essence, the overhead transmission system is more vulnerable to environmental externalities but is also restored to normal state in an expedient manner. Due to the distance between conductors of an OHTL of several meters, their specific capacity is rather low compared to the specific inductivity. In a report by ECOFYS it is stated: “Given the extensive track record of OHTL projects reliable information about specific costs is available. The cost for the conductors amounts to roughly one third of the total cost of a typical 2-system HV OHTL.” [7]

In the case of the UGTL, trenches need to be dug where cables are laid either directly buried in ground or in ducts. The ducts can be either concrete encased or plastic pipes (PVC). The cables need joints in regular intervals because of weight and handling constraints for the typically heavy cable.

Compared to underground cable, the specific capacitance is 12-26 times lower and the inductivity 3-4 times higher for an OHTL. Reactive power does not contribute to the desired power transmission, but contributes to line loading and losses. Additionally, with long lines these charging currents become an engineering issue (energizing, testing, voltage profile, etc.). For that reason, the reactive power of an underground cable may need to be compensated at distances of as short as 40 km for 132/220kV lengths

[7] by shunt reactors. However, through accurate and unprejudiced network analysis and system design, including installation, the compensation length can be significantly increased for cable systems circuit lengths without reactive compensation [8]. Also, the compensation design, if required, can be such that the compensation occurs at each end point of the cable or at its switching station. Thus, it may not be unreasonable to expect that a single circuit cable at 132kV could be 120 km long without any compensation reactors required along the cable length (only at its endpoints).

The most important technical differences between OHTL and UGTL are insulation, thermal heating and installation techniques. In overhead lines, air acts as the insulating medium around the bare conductors attached to overhead structures. Based on the clearance requirements at different voltage levels and structure design, each conductor is spread wide apart from each other and the ground. In the case of underground lines, a heavy insulating medium has to be in place. Earlier generations of cable had oil impregnated paper as the insulation. The oil was borne in the cable via a pressured oil-duct through the center. Another type of insulation had high pressure fluid, e.g. nitrogen or oil, and was covered in a steel shielding. More recently cross-linked poly ethylene (XLPE) insulated cable has emerged as the most preferred cable for low to extra high voltage applications – see Figure 8 for an illustration of both types of cable. They are of a dry type and essentially maintenance free till they fail. These cables have totally different characteristics than the previous generation of cables and one need to be very careful when utilizing life time and reliability statistics from historical cable installations as these would be mostly derived from the older types. Unfortunately, much of the statistics that is often presented when comparing overhead lines and underground cables have included these older types of cables.

Figure 5: Typical Sample of a 500 kV, 2500 kcmil XLPE Cable

All conductor losses are directly due to the resistivity of the cable. In the case of underground cable, the losses are also due to induced current in the cable sheath and the insulation layer around the conductive medium. For overhead conductors air acts as the thermal conducting medium to dissipate the heat whereas in the case of underground conductor, the soil can hinder the proper dissipation of heat generated in the cable. Typically, XLPE underground cable conductors have a maximum operation temperature of at about 80 to 90 °C with an emergency operating temperature of about 130 °C [9]. The selection of cable with lower resistivity, larger cross-section and transmitting energy at higher voltages are ways of mitigating the loss impact.

Costs for UGTL construction is significantly higher in urban areas as the existing infrastructure has to be supported and carefully handled whereas in rural areas mechanical diggers can be used without obstruction. In all cases when building a new UGTL, additional costs and care will be required to preserve the natural environment and existing infrastructure, e.g. rivers, roads, wetlands, lava fields, etc. When laying the cable inside trenches, it can be laid in a triangular bundle, or laid side by side. Each technique has its own merits but can affect the cost, electrical conductivity (distance between cable and heat generated), future ability to maintain, as well as repairing and restoration of faults. Some of the techniques used in the excavation of soil include horizontal drilling and running conduits, U or V shaped trenched (in rural land), pipe jacking and micro-tunneling. Trenches for UGTL are typically 1.5-2 m deep to keep them below the frost line [9]. The other factor affecting the construction is joints and terminations. Vaults need to be dug when joints are required and they are traditionally over 3 m each way (length, breadth and height) or bigger. When underground sections of the cable have to be transitioned to an overhead section, termination structures have to be built for the continuity of the current flow and transition of construction. These differences are all major considerations when building OHTL and UGTL and overall costs can be significantly different based on the circumstances.

6. Cost Estimation

The actual project costs incurred on a specific project is heavily dependent upon many specific factors and a detailed estimate should be performed for an accurate estimation. The cost estimation provided below in Table 2 is a general estimation.

Table 2: Cost Estimation

Cost category for 1000 kcmil 132 kV high voltage cable	**Procurement cost per single phase/km [2] (M€)**	**Installation cost per single phase/km [2] (M€)**	**Number of cables**	**Estimated length (km)**	**Total Cost for Procurement and Installation**	**Cost of Losses (M€)**	**Total cost (M€)**
Replacing existing 132 kV overhead line (MJ1) with 132 kV cable	**0.05**	**0.23**	**3**	**81**	**68.04**	**1,18**	**69.22**

Cost category for 1000 kcmil 66 kV high voltage cable	Procurement cost per single phase/km (M€)	Installation cost per single phase/km (M€)	Number of cables	Estimated length (km)	Total Cost for Procurement and Installation	Cost of Losses (M€)	Total cost (M€)
Replacing existing 66 kV overhead lines(BD1 + TA1 +BV1+IF1) with 69kV cable	0.04	0.23	3	BD1= 36.4 TA1= 45.1 BV1= 17.1 IF1= 14.7 **Total length = 113**	91.53	0.59	92.12

Forty year loss costs are estimated at €21.25 per MWh for the calculation (3.5 IKR/kWh) with an escalation of 3% per year – typically in Europe a cost of €40 per MWh are used for this purposes but costs in Iceland are lower. For this general example the amount of losses is roughly estimated as 2% with an average load of 50 MVA for 69 kV and 100 MVA for 132 kV.

Table 3 below shows Total Cost (purchasing, installation and cost of losses). Installation cost (earthworks, cable laying and finishing) for underground cable is about three times more than the material cost. This is a large part of the investment cost and it can vary significantly between projects, depending on site conditions and project requirements. METSCO decided to use the social cost of energy supplies of reference [1] which is 400 million kronur per year.

Table 3: Total Cost and Reliability

Cost and Reliability estimation	Total Cost (M€)	Reliability (failure rate) per 100Km/year
Doing Nothing	Social cost per year 3.26 [1]	14 [1]
Replacing existing 132 KV overhead line (MJ1) with 132KV cable-approximately 81 km	69.22	0.28 [2]
Replacing existing 66KV overhead lines (BD1 + TA1 +BV1+IF1)- with 69KV cable approx.- 113km	92.12	0.15 [3]

7. Reliability and Availability of Power

Overhead and underground systems are impacted differently; overhead systems are exposed to weather and contaminations such as volcanic ash while underground cables are generally not affected by environmental disturbances. Soil reinforcement might be required for strength and stability of overhead structures and re-enforced concrete ducts can be used to counter unintentional damage to cables. Major earthquakes do occur in Iceland and in the case of one occurring; the underground transmission lines are often believed to be more vulnerable than overhead lines although evidence from previous earthquakes has not supported that view. Failure patterns would vary by location, design, weather, environment, awareness, standards and other factors. In the case of faults, locating faults in overhead lines is easier. Once located visually, the restoration process can start. Due to ease of accessibility, overhead failures on average can be fixed within a few days (typically 1 day for minor failure and 5 days for major failure – average outage time for Landsnet's 220 kV system is 6.9 hours per failure [10] but that may also include momentary outages). Historically underground failures take longer to locate and restoration of XLPE type can last 5-9 days based on factors such as condition of equipment, availability of replacements, ease of access, and expertise of workers [9]. This results in an unavailability of cables being higher than that of overhead lines, in this case by a factor of approximately two as is seen in table 4 below. However, failure data for XLPE cables is being conservatively estimated as they have not been utilized for many years and failure rates are very low.

Table 4: Reliability Estimates

Reliability Estimates	Failure Probability Per year/100 km	Average Duration Hours	Unavailability Hours per year
220 kV Overhead Line (Landsnet report) [10]	0.4	6.9	2.76
132 kV overhead line (Vesturlina) based on 2013 data [1]	3	3	15
66 kV overhead lines(BD1 + TA1 +BV1+IF1) based on the 2013 data [1]	14	5	90
XLPE Underground Cable (Estimate) [11]	0.03	168 (7 days)	5.0

It should be noted that unavailability as shown in the above table does not necessarily mean outages to customers as transmission systems are normally designed with at least N-1 contingency which allows for at least one failure to occur without causing customer interruptions; this is the case with Landsnet's system. Therefore, the chances of two transmission system sections being unavailable at the same time are very low especially in the case of underground cables which have both a very random and low occurrence of failure. On the other hand, as overhead lines are more susceptible to storms, the chances of simultaneous unavailability of two or more overhead lines is much higher which could result in large scale customer outages. The data shown in the table doesn't account for the likelihood that the overhead experiences many momentary outages that may cause voltage sags or short outages to customers.

8. Challenges with Underground Cables

There are also some disadvantages regarding undergrounding of cables. In 2014 a group of experts in the field of high voltage cable and cable installation from Iceland and Denmark worked with Landsnet in an extensive project concerning the installation of 132 kV and 220 kV circuits. The study showed that the location of individual cable projects in Iceland is affected by both technical constraints of the transmission system, and by site conditions. The short-circuit capacity varies significantly between the southwestern part of Iceland and the north. Furthermore, the weaker parts of the system feature very low short-circuit values. This is most likely going to be the greatest physical restraint to limit potential cable lengths. Phenomena such as excessive voltage levels during low load conditions, and low resonance frequency values represent technical limits to cable lengths for each project [2].

There are different mitigation techniques for issues such as voltage rise, temporary overvoltage (TOV) and resonance in EHV cables (extra high voltage, 220KV and above), listed as below [14]:

- Management of existing reactive compensation equipment or adding shunt capacitors/reactors
- Changing of operating procedures
- Modification of switching / energization procedures
- Using surge arresters
- Dynamic reactive compensation

In a study about switching over-voltages in 60 kV reactor compensated cable in Denmark, presented in reference [15], it was explained that the large capacitance of the cables makes the underground cable system produce 20-30 times more reactive power than the overhead line. A solution to the excessive reactive power production is to connect reactors into the 60 kV grid. A possibility is to connect those reactors directly to some of the cables to compensate for the reactive power production in such a way that the reactors are switched on and off along with the line and thereby reduce the changes in the reactive power balance in the grid and reduce cost of by using the reactors instead of switchgear. This is known to have been done on a 400 kV transmission line from Ferslev to Trige in Denmark where the line is a combination of overhead line and underground cable. Measurements on that line have shown resonance over-voltages up to 32 % for a period of several seconds occurring after disconnection of the line.

As over-voltages due to resonance are known to occur on 400 kV combined overhead underground grids, the study on a 18.5 km underground cable line operating at 60 kV revealed there was no significant over-voltage during switching except when the mutual coupling of the systems are significantly large and the system is unbalanced. It was also found that with the expected reactor parameter values no harmful over-voltage will occur during switching.

All of above studies shows that in replacing overhead lines with underground cables the possibility of some issues should be considered and studied. Reactive power compensation and the possibility of switching over-voltage due to resonance of capacitance and inductance should be carefully studied.

Table 5: Approximate Length of Overhead Lines

132 kV and 66 kV lines in Westfjords	Voltage level (KV)	Length of over head lines(km)
Mjólká Line 1 (MJ1)	132	81
Breiðadal Line 1 (BD1)	66	36.4
Tálknafjardar Line 1 (TA1)	66	45.1
Bolungarvíkur Line 1 (BV1)	66	17.1
Isafjordur Line 1 (IF1)	66	14.7

Table 5 above summarizes the approximate length of the overhead lines studied in this report. The 66 kV lines including BD1, TA1, BV1, and IF1 have substations between them which can help to control the over-voltage and resonance issues by using appropriately sized surge arresters and reactors. The 132 kV MJ1 line is 81 km long which requires more attention to control the over-voltages. Each underground cable circuit is unique, so that in each case, system design modelling needs to be done to confirm practicality and ensure compatibility with the network. A detailed modeling is required to review the condition of the system and propose practical options.

The other obstacle is thermal dissipation of the soil. Thermal dissipation of the soil surrounding underground cables affects the capacity of the cable. Thermal conditions in Icelandic soils are quite unfavorable. National average of thermal resistivity of in-situ soil is 1.5 K*m/W, while the average for West areas is 1.8 K*m/W. Values for resistivity of backfill material should not be estimated lower than 1.3- 1.5 K*m/W, given favorable conditions. For comparison, thermal resistivity of 0.8 K*m/W is used as a reference value for Danish backfill material. Therefore, the capacity of the same type of cable is around 30% higher in Denmark [2]. It would be a great benefit if the thermal dissipation of the soil surrounding the cables could be improved.

9. Other Considerations

9.1 Safety

Safety around electrical equipment is a major concern of any company in the electrical sector. Working on or around existing electrical equipment is a part of modern life for hydro workers and also for the general public. The risks are escalated in the case of high voltage transmission lines. Best safety standards have to be followed in the design of the lines and during the construction stages of the projects. Building residences under or over the ROW is not recommended. The biggest risk is the direct contact to energized lines and with ground at the same time. Fallen lines due to failure, lightning, wind, icing and/or storms can pose this threat if the lines continue to be energized. In the case of underground transmission, people or equipment can dig into the ground and contact risk can occur. Completely cordoning off ROWs, installing cable inside concrete encased ducts and adequate protection schemes are ways of mitigating or in some cases eliminating these risks.

In general, many of the public safety concerns can essentially be eliminated in the underground option. The weather and accessibility risks will continue to remain in any overhead design.

9.2 Right of Way

In general, building an UGTL is far more complex than building and OHTL. While some of the considerations are general in both types of construction, some are very unique to the underground option.

In the case of transmission corridor or ROW selection, securement and construction execution, several key steps need to be considered that can have an impact on the overhead or underground lines during their useful life. There are many considerations when selecting routes for the lines. Pre-existing contamination, local habitat disruption, and unregistered private landfill that can present obstructions to the boring or drilling process. In the case of urban development, the ROW goes through local neighborhoods causing specific concerns amongst the neighboring constituencies. Water bodies in the path of the ROW can cause water erosion into the excavation site causing seepage into the ducts supporting cable. The other key issue is ensuring the underground ROW remains protected during its entire lifecycle. In underground construction, grading adjustments and heavy equipment digging can damage the duct structure and in turn damage the cable. This can cause significant outages to many people and have monetary impact on businesses and society in general. This requires acquiring proper land surveys, and having indemnity agreements and easements in place to control landscaping, tree-planting and storm water re-direction around the underground ROW.

9.3 EMF

Electromagnetic fields (EMF) are created around cable or conductors when they carry current. With higher voltage the higher the strength of the electric field becomes and with higher current the higher the magnetic field becomes. These fields are prominent around the bare conductors in OHTL but are obstructed by the surrounding insulation material in the UGTL. At ground level, there is no electric field due to the shielding in the underground cable and the magnetic field falls off much more rapidly with distance than those from overhead power lines. However, the ground level magnetic fields can actually be higher close to the underground cable. The strength of the magnetic field produced by a particular transmission line is determined by current, distance from the line, arrangement of the three conductors, and the presence or absence of magnetic shielding.

Underground transmission lines produce lower magnetic fields than above ground lines. The underground conductors are placed closer together which causes the magnetic fields created by each of the three conductors to cancel out some of the fields created by the other conductors. Magnetic fields are also strongest close to their source and drop off rapidly with distance. This phenomenon impacts the way the cables are installed in the ground; the closer the cables, the lesser the EMF, but there are practical limitations to how close cables can be placed.

The electric field outside of an underground cable approaches zero because of the shielding effect of the neutral and armored jacket. Overhead lines generate electrical fields that can easily reach to the ground level. Audible corona noise generated by high electric fields is another drawback of the overhead lines.

9.4 Environment

OHTL and UGTL both impact the environment to some degree but steps can be taken to mitigate the impacts. Environmental Assessments are required in most jurisdictions that requite a high level of mitigation on the natural environment and also on property values and culture. Several steps during the design, construction and post construction phases can be taken to minimize the impacts. Some of the important factors are selection of equipment considering environmental sustainability, aesthetic design, timing of construction, restoration and species management.

During the replacement or upgrading of transmission lines, a few factors would definitely impact the surrounding environment and might add to the cost of building the line. A detailed transmission design analysis and construction estimate needs to consider this additional impact and also its monetary effect.

For overhead lines, agriculture underneath is possible but there could be impacts such as soil erosion, increased weed and pest infestation, soil mixing, rutting and compaction. For underground lines, these direct impacts are minimized but still, the ROW land predominantly is secured but can still be used for general agricultural purposes. Waterways in the form of rivers, lakes, streams can also be impacted more for underground cable installation than overhead lines, however successful maneuvers around rivers in the construction of Kopasker–Bruarland 33kV underground cable in the 1990s show how that can be managed successfully.

Important considerations in Iceland are the abundance of untouched nature and scenery. It is considered valuable to have as much as possible of this extraordinary landscape remaining unchanged. Building very visible transmission lines can be quite contrary to that value statement as overhead lines can have strong visual impacts on the environment. That becomes particularly important in the Icelandic context, where landscape is frequently open, often with a wide horizon, and large wilderness areas are among the last remaining in Europe.

9.5 Tourism and local economy

Tourism is a big contributor to the Icelandic economy and the number of tourists coming into Iceland continues to grow over the last decade. The beautiful Icelandic landscape and natural habitat along with its unique climate are major drivers for people all over the world to visit. According to a report published on Icelandic tourism in 2010, the share of tourism in Iceland’s GDP was 6%. Tourism’s share in export revenue between 2009–2012 was between 18.8% and 23.5% according to measurements of the export of goods and services. Foreign visitors paid approximately €1.45B to Icelandic companies in 2012 according to measurements of service transactions. The growth in spending was around 21% between 2011 and 2012. When account is taken of price changes, the real growth was approximately 14%. At fixed-price levels, the spending of international visitors has increased by almost 30% from 2009 to 2012 [12]. This trend is expected to increase in future years with increasing benefits to the Icelandic economy. It can be recognized that preserving the natural views and habitat is important to the country. Building transmission lines underground is the natural choice in that regard. Studies have shown that this does affect people´s perception of unspoiled nature [13] . When evaluating options it is very important to consider the effect on this major economical driver.

10. Conclusion and Recommendations

Undergrounding transmission lines is a financially viable choice for long term return on investment. This option has other benefits such as enhanced safety, lower environmental impact, aids in the maintenance of Iceland's natural habitat and may support the growth of the tourism industry. When evaluating options, such as those discussed in the report, it is important to consider all life-cycle costs and not only initial construction costs. Only then can a true comparison be made.

As mentioned before, in Iceland, there are different opinions for increasing the energy security in Westfjords . In winter 2013-2014 longer faults occurred on transmission systems as a result of ice loading on the overhead lines. By replacing overhead lines with underground cables, outages will be significantly reduced. The main benefits of underground cables compared to overhead lines include better aesthetics, lower line losses, lower operating costs and essentially immune to the effects of storms, vulcanic ash, salt contamination and icing. The main advantage of overhead lines is that they are less expensive and simpler to construct, easier to repair and less affected by thermal loading.

Based on the limited statistics and data available, the failure rates of 66 kV and 132 kV lines at Westfjords are very high. The average failure rate for 66 kV line (BV1) based on 2013 data is 14 /100km/year and for the 132 kV line (Vesturlina) is 3/100km/year. By using underground cables this failure rate can be improved significantly up to 0.28/100km/year.

The useful life of modern underground cables is expected to be at least 60 years where care is taken during the installation and load management. Overhead lines are less sensitive to installation and loading but they are directly susceptible to storms and icing loads which in the extreme has led to major, premature rebuilds in many countries.

Other advantages of underground cable options generally include fewer safety risks, less EMF exposure, elimination of corona discharge, and less environmentally intrusive. It can be in the public interest for utilities to be accommodated on road right-of-ways when such use and occupancy do not adversely affect safety, construction, maintenance or operations. Often underground cables can be installed beside roads to minimize land disruption and allow easier access. This could be an option for the new 66kV and 132 kV underground circuits.

When deciding between overhead, underground or other options such as a power plant to mitigate energy security risks, total costs should also include the benefits to customers, costs of outages, and benefits for the overall economy. It is important to strike a balance in stakeholders' interests and recognize the impact on businesses, communities and the economy as a whole.

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