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Technical and Economic Comparison of 30 kV Underground Cable and Fully Covered Conductor Solutions

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Scope of the thesis is to provide the product management team of Ensto Oy's DSO business unit with an economic and technical comparison of a 30 kV fully covered conductor and underground cable line. The thesis compares two imaginary lines with a length of approximately 20 kilometers.

By utilizing methods of distribution network calculations, such as power losses, voltage drop, annuity and discount calculations, approximate technical and financial results made comparison possible for both line types. The components of the network were not selected based on calculations, because they were given in the starting information of the thesis. Finnish electricity transmission and distribution system and factors affecting loadability of a power line were introduced briefly in the thesis.

The result of the thesis work provide an approximate result of the life cycle costs and technical parameters of both lines. In addition, the work involves comparison of the results obtained and choosing the more profitable line type.

According to the comparison, underground cable line Class 1 was chosen as the more profitable line in terms of economic results. However, the FCCS line is able to transmit more power. If underground cable line Class 2 had been chosen, the FCCS line would be more profitable in terms of economic and technical results. Based on the results, the product management team of Ensto Oy's DSO business unit obtained the necessary calculation methods to perform similar comparison for new objects.

Keywords	Fully Covered Conductor Solution, Underground Cable, Costs

Tekijä Otsikko Sivumäärä Aika	Markus Kohtamäki 30 kV:n maakaapeli- ja päällystetyn ilmajohtojärjestelmän teknis-taloudellinen vertailu 36 sivua + 2 liitettä 16.12.2020
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Opinnäytetyön tarkoituksena oli tuottaa Ensto Oy:n DSO-liiketoimintayksikön tuotehallintatiimille teknis-taloudellinen vertailu 30 kV:n päällystetystä avojohto- ja maakaapelilinjasta. Työssä vertailtiin kahta kuvitteellista linjaa, joiden pituus on noin 20 kilometriä.

Sähkönjakeluverkon laskentamenetelmiä, kuten tehohäviö-, jännitteenalenema-, annuiteetti-, ja diskonttauslaskelmia hyödyntämällä mahdollistettiin likimääräiset tekniset ja taloudelliset tulokset, joiden avulla linjatyyppejä pystyttiin vertaamaan toisiinsa. Työssä ei valittu verkon komponentteja laskelmien perusteella, vaan ne ovat annettu työn pohjatiedoissa. Opinnäytetyössä esitetään myös Suomen sähkön siirto- ja jakelujärjestelmää ja linjojen kuormitettavuuteen vaikuttavia seikkoja.

Työn lopputuloksena saatiin likimääräinen selvitys molempien linjojen elinkaarikustannuksista ja teknisistä parametreista. Lisäksi työhön kuului saatujen tulosten vertailu ja kannattavamman linjatyypin valitseminen.

Vertailun kannalta maakaapelilinja luokka 1 oli PAS-linjaa kannattavampi taloudellisesti. Kuitenkin PAS-linjalla voidaan siirtää enemmän tehoa. Jos maakaapelilinja luokka 2 olisi valittu, olisi PAS-linja kannattavampi niin taloudellisesti kuin myös teknisesti. Tuloksiin pohjautuen Ensto Oy:n DSO liiketoimintayksikön tuotehallintatiimi sai opinnäytetyöstä tarvittavat laskentamenetelmät, joilla samankaltainen vertailu voitaisiin suorittaa uusille kohteille.

Avainsanat	päällystetty avojohto, maakaapeli, kulut

Contents

List of Abbreviations

A	Ampere
AAAC	All Aluminium Alloy Conductor
AAC	All Aluminium Conductor
AC	Alternating Current
ACSR	Aluminium Conductor Steel Reinforced
Al	Aluminum
CLD	Current Limiting Device
DSO	Distribution System Operators
ENS	Energy Not Supplied
FCCS	Full Covered Conductor Solution for Overhead Line Systems
kV	Kilo Volt
kWh	Kilowatt-Hour
Mg	Magnesium
MV	Medium Voltage
MVA	Mega Volt-Ampere
MVAr	Mega Volt-Ampere reactive
MWh	Megawatt-Hour
OHL	Overhead Line

PF	Power Factor
Si	Silicon
SVL	Sheath Voltage Limiter
XLPE	Cross-linked Polyethylene

1 Introduction

Scope of this thesis is to produce a technical and economic statement and comparison of medium voltage fully covered conductor- and underground cable solutions. The thesis research was made for Ensto Distribution System Operators product management team that is located in Porvoo, Finland.

Subject of this thesis research was needed because product management team does not have enough information concerning which line-type is more profitable. Ensto has full product catalogue for 30 kV fully covered conductor and underground cable accessories and therefore this thesis research could partly be utilized as marketing material. Product management team wants to know which line-type is more profitable in terms of investment, construction, and operation costs and which line has higher power transmission capacity. In addition to economical results, both line-types are compared with each other according to technical calculations. Length of the lines is 20 kilometers and FCCS comparison line is a double line. Underground cable is a single with equal ampacity with the FCCS line. Used conductor cross-sections are listed below in the thesis.

Compilation of the results of the thesis research utilizes dimensioning and calculation methods of a power distribution network including voltage drop, power loss and reactive power calculations and economical results were made possible with annuity and discounting calcultions.. The client of this thesis research gave boundary conditions for the comparison lines and they are listed in Chapters 5 and 8. Protection of the lines and fault current calculations are not introduced in this thesis. The thesis also focuses on elements that affect power transmission capacity of a medium voltage power line. Power transmission and distribution system of Finland is briefly introduced.

The thesis does not present exact component prices for medium voltage line accessories or conductors as they are classified as trade secrets. Economic results that include component related prices are reported in the form of EUR per kilometer. However, cost of power losses, interruptions and total life cycle costs are reported as bulk price.

2 Ensto

Ensto is a Finnish family business established in 1958 by Ensio Miettinen. Head office of the company is located at Porvoo, Finland. Ensto has two business units: Ensto Building Systems and Distribution System Operators. Building Systems offer solutions for building electrification e.g. electric vehicle charging, heating systems, lighting, and cabling management solutions. Distribution System Operators offers accessories such as e.g. connectors and conductor terminations for low, medium, and high voltage overhead- and underground line solutions including network automation, power quality, and smart grid products.

Ensto has several offices and production sites across Europe, India, Russia, and the United States of America. Ensto has seven main production sites and sales organizations in 20 countries. Ensto is employer of approximately 1600 people around the world and turnover of the company was 266 M€ in 2018.

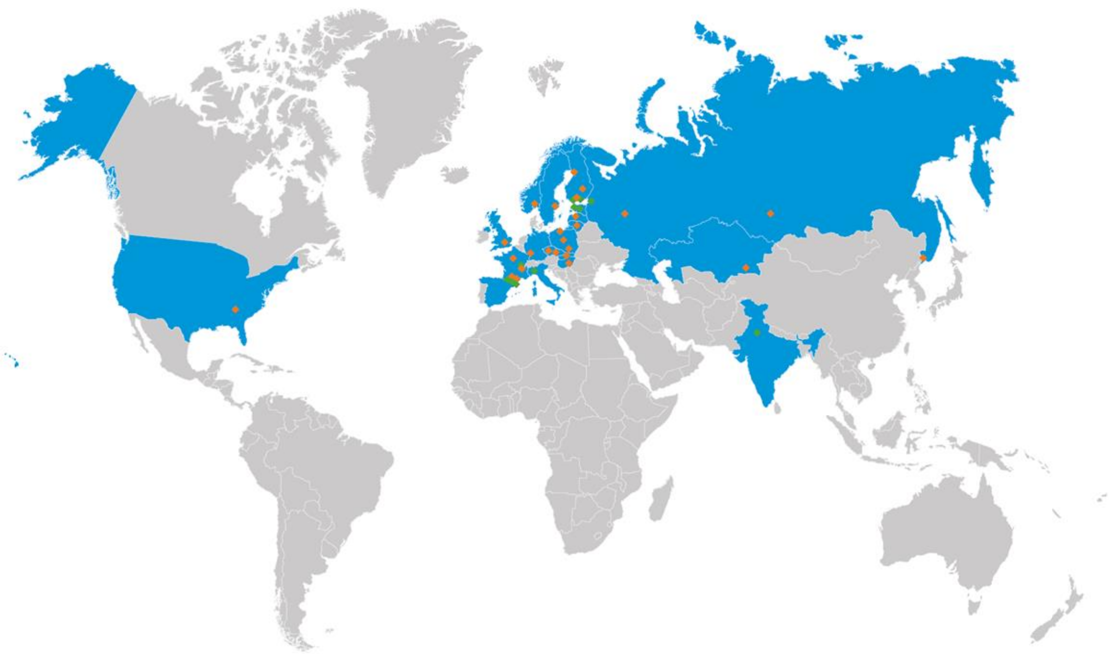

Figure 1. Ensto offices and production sites [15].

3 Transmission and Distribution Network of Finland

Finnish power transmission system consists of high voltage 400, 220 and 110 kV lines, which are mainly overhead lines. The entity is called stem network and it is shown in Figure 1 and it is owned and operated by Fingrid Oyj. Local specific energy companies manage distribution network, which delivers energy to customers, e.g. households and industrial production sites. Distribution networks consist of high voltage 110 kV lines, medium voltage 10-45 kV lines and low voltage lines under 1 kV.

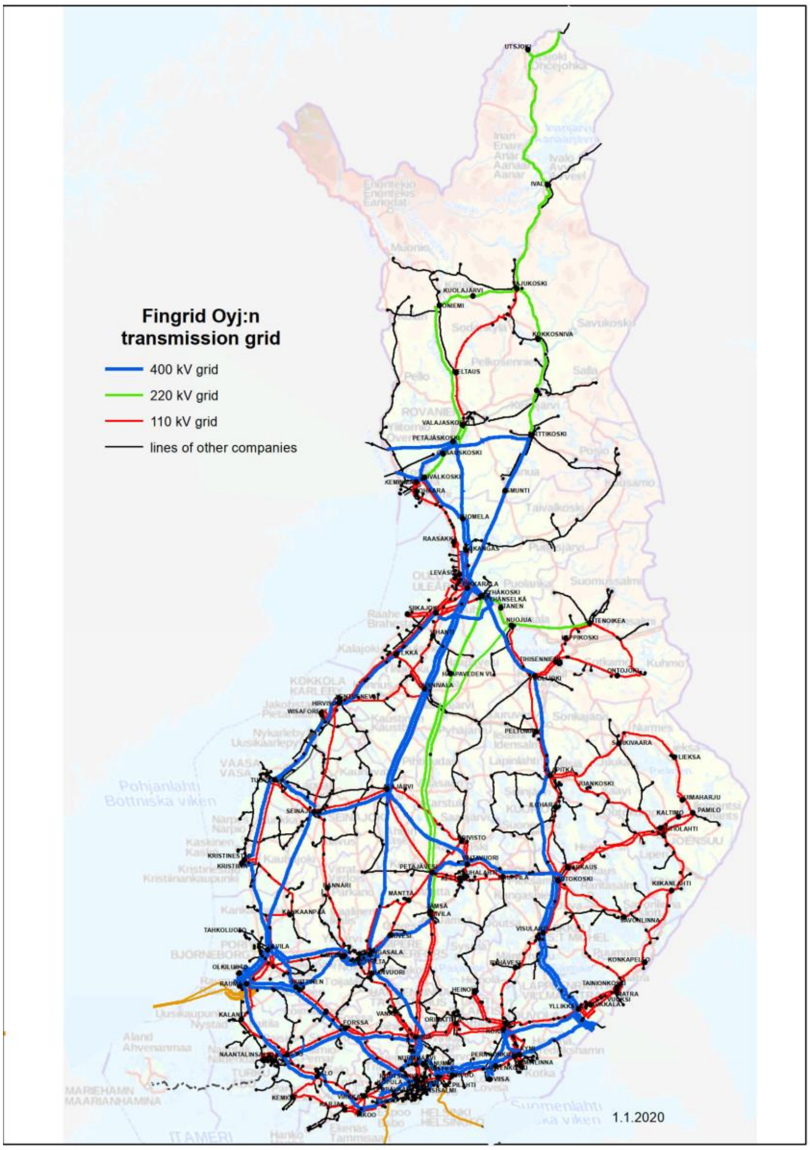

Figure 2. Power transmission grid of Fingrid Oyj [10].

3.1 Medium Voltage Network

Finnish medium voltage network consists of 800 substations and 150 000 kilometers of medium voltage lines, which are mainly bare overhead lines. However, cabling and fully covered conductor systems are becoming more popular as new technology emerges and delivery reliability requirement of electricity is being increased [1, p.11].

3.2 Overhead Line

Medium voltage overhead lines of Finland are either bare- or covered conductors. Bare overhead line is the preferred option due to its low cost. Covered conductor solutions are 30-40% more expensive and are suitable for double- or even triple lines, or for challenging conditions e.g. locations, where snow burdens on the lines. Overhead lines are almost without exception constructed on wooden poles, since they are suitable for Finnish weather conditions and are rather cheap option. Typical hold time of a wooden pole is approximately between 25 and 50 years. [1.]

3.2.1 Bare Overhead Line

Bare overhead lines are the preferred option because they are cheap to build and easy to extend if needed. In Finland, the most popular bare conductors are AAC (All Aluminum Conductor) and ACSR (Aluminum Conductor Steel Reinforced). AAC is purely aluminum and ACSR has steel wire running through the core.

3.2.2 Fully Covered Conductor Solution

Covered conductors are constructed from the core conductor, which is aluminum alloy, usually Al-Mg-Si. The core is covered with semiconducting layer and a XLPE insulating layer. The most popular covered conductors are BLL-T and SAX-W. Due to the insulating layer, phase-to-phase spacing for covered conductor solutions is half a meter smaller than compared to more traditional bare overhead lines where the phase distancing is approximately 1 meter. Figure 4 shows a typical double FCCS line layout. Laying branch on the conductor or contact of phase conductors will not cause tripping of protective devices. However, the insulation of covered conductors does not protect against contact of hand-live conductor. Covered conductors should always be handled with proper live-line tools. [1.]

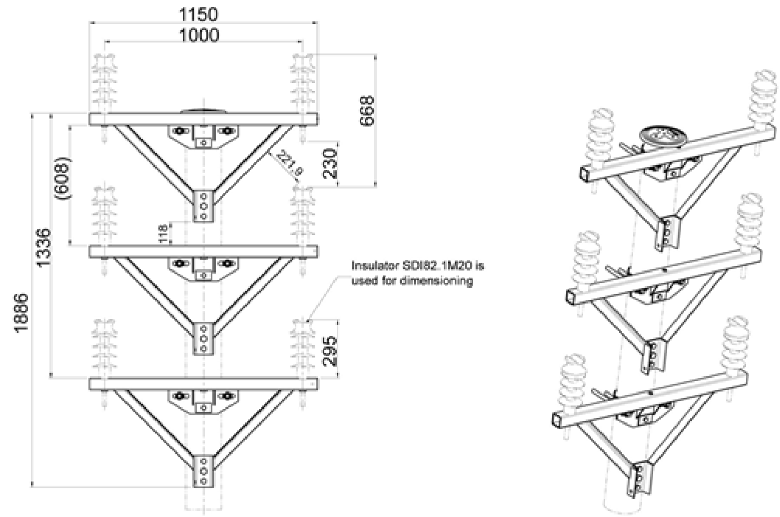

Figure 3. Typical FCCS double-line cross arm setup [15].

FCCS-lines are usually located next to roads and highways, since it is recommended, that the lines should be inspected after every storm. If covered conductor is damaged, the repairing process is slightly more complicated than compared to more traditional bare overhead line due to the insulating layer. Earlier FCCS lines were difficult to repair because heat shrink technology was used. Ensto has developed Cold shrink technology accessories for covered conductors, which means that repairing a FCCS line does not need gas burner. FCCS lines should also be equipped with current limiting devices (CLD) since a burning electric arc could cause complete breakdown of the conductor. Figure 4 shows a typical principle of the current limiting device. [1, p.145.]

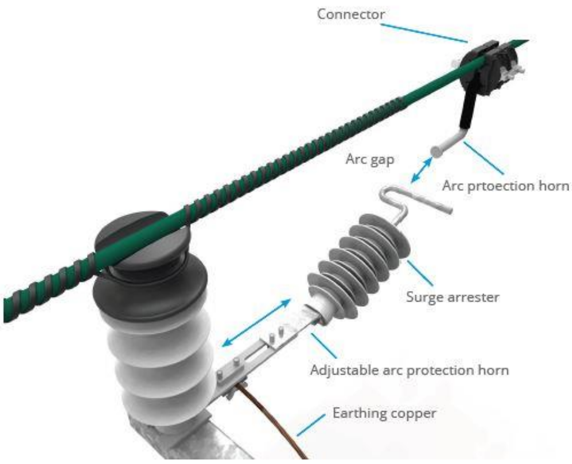

Figure 4. Current limiting device of a FCCS-line [14, p.8].

3.3 Underground Cable

Finnish transmission and distribution systems mainly use cable solutions for low voltage, medium voltage and high voltage networks up to 110 kV. However, manufacturing readiness has been developed for 400 kV cables. Cross-sections of cables are typically from 25 mm^2 to 2500 mm^2. Smaller cross-sections are for low voltage applications because high voltage and small cross-section causes electric field strength to rise to a high level and decreases dielectric properties of the cable. [13. 1.]

Figure 5. AHXAMK-W 18/30(36) kV Medium Voltage Aluminium Power Cable [19].

Power cables have industrially produced jacket that protects the cable against moisture, corrosion, and mechanical damage. Main structural components are core conductor, conductor screen, conductor insulation, corona shielding, and protection against contact and external protective layers such as jacket, armoring and corrosion protection. Figure 5 demonstrates the construction of a popular AHXAMK-W cable. [13, p.373.]

3.3.1 Metallic Sheath Bonding

Metallic sheath of an underground cable is usually grounded from one or both terminal points. Alternating current flowing through the core of the underground cable induces voltage to the metallic sheath of the cable. This induced voltage causes circulating currents if the bonded metallic sheaths becomes a closed circuit. High amount of circulating sheath current significantly reduces the thermal loading capacity of the conductor. Purpose of the metallic sheath is to ground charging- and fault currents while the cable is in service. [11.]

3.3.2 Solid Bonding

Solid bonding is commonly used with low and medium voltage cables, because it is economical option due to its low cost and simplicity. Solid bonding means that the both ends and intermediate points of the metallic sheath are grounded. This is shown in Figure 6. When both ends are grounded, closed circuit is formed and circulating current starts to flow. Ampacity of the cable will be reduced significantly due to the circulating current, which reduces conductors' current carrying capacity due to joule losses. [11.]

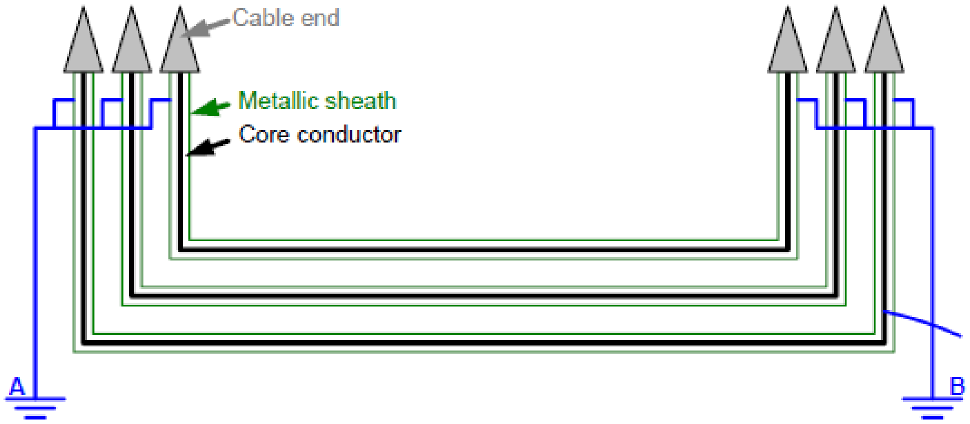

Figure 6. Solid bonding system. [11.]

3.3.3 Single Point Bonding

Single point bonding configuration is a system where only one end of the cables metallic sheath is bonded. Other end of the sheath is grounded through a sheath voltage limiter, also known as SVL. Fundamentally, SVL is a surge arrester with its own name. Purpose of the SVL is to maintain the potential difference between metallic sheath and earth during transients, at a level, which will not puncture the jacket of the cable. [12.]

Single point bonding method allows higher current carrying capacity because the bonding system does not form a closed circuit and therefore circuiting current losses are not present. Figure 7 exemplifies the single point bonding system. [11.]

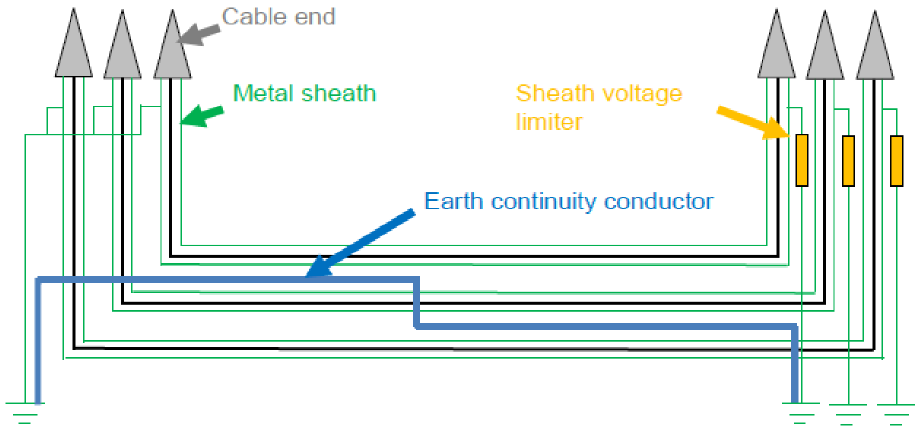

Figure 7. Single point bonding system. [11.]

3.3.4 Cross-bonding

Cross-bonding joints disconnects the sheath continuity by grounding the sheath at every cable joint, Figure 8 shows the bonding system. Connections should made in a way where the three phases are connected consecutively and since the three phases are ideally, in 120° phase shift, the induced voltages in the sheath are reduced and therefore the circulating currents are reduced. The sheaths are grounded through a SVL to protect the cable jacket, e.g. in a situation where sheath is suddenly disconnected. Unwanted disconnection of sheath bonding induces high sheath voltage and it could puncture the cable jacket in the worst scenario. [11.]

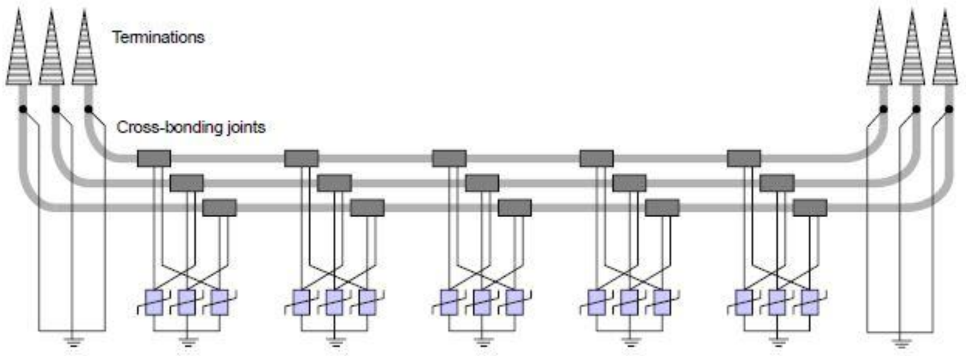

Figure 8. Continuous cross-bonding system. [11.]

Even though the induced voltage and circulating current can be reduced by adding more cross-bonding joints to the line, it is not economically ideal. Circulating current and induced voltage cannot be completely compensated from the sheath and it is essential to consider this factor during design phase. [11.]

3.4 Earth Fault Protection

Due to Finland's poor earthing conditions, star points of medium voltage network are usually isolated from the ground, or they use so-called special form of the above-mentioned, called resonant earthed system. Resonant earthed systems have inductive earthing reactance connected to the star point of the network, which approximately corresponds to reactance caused by earth capacitance of the network. The main reason for the chosen earthing systems is magnitude of contact voltage. Acceptable contact voltage is dependent on the duration of contact and magnitude of the voltage. [1, p.182.]

4 Transmission Capacity

4.1 Thermal Loading Capacity

Thermal loading capacity declares the maximum current, which does not raise the temperature of the conductor above nominal operating temperature. Overloading the conductor heats up the insulation and decreases its dielectric strength, which can result in flashover or a complete breakdown. Underground cables can withstand short term overloading without any greater damage to the insulation or conductor because the soil surrounding the cable works as a heatsink until the temperature of the soil has close enough of the conductor's temperature. Overhead lines, however, can withstand long term overloading because of air insulation, which conducts heat away from the conductor more effectively for longer time. The length of the overloading can vary depending on environmental conditions. For example, during winter overhead lines can withstand overloading for longer period, due to freezing conditions. [4, p.304-305.]

Nominal current according to maximum operating temperature is declared in the datasheet of a conductor. If supply voltage and current are known, the theoretical maximum transmittable power can be calculated. Apparent power determines cross section of suitable conductors because AC circuits usually have a reactive component, since the conductor itself has resistive, inductive, and capacitive components and therefore active power cannot be used as the dimensioning factor.

Transmission capacity differs essentially with different installation methods. Recommended thermal loading capacity for PEX insulated conductors is 90 ˚C in air and 65 ˚C buried. Following Tables 1 and 2 have correction factors for PEX insulated conductor's ampacity according to ground temperature and laying depth.

Table 1. Rating factor for buried cables rating correction according to ground temperature [16, p.11].

Rating factor for ground temperature								
Conductor temperature [˚C]	Ground temperature [˚C]							
	10	15	20	25	30	35	40	45
90	1,07	1,04	1	0,96	0,93	0,89	0,84	0,8
65	1,11	1,05	1	0,94	0,88	0,82	0,74	0,66

Table 2. Factor for buried cables rating correction according to laying depth [16, p.11].

Rating factor for laying depth	
Laying depth [m]	Rating factor
0.5	1.1
0.7	1.05
0.9	1.01
1	1
1.2	0.98
1.5	0.95

4.2 Transmission Voltage

Medium voltage network of Finland uses mainly 10, 20 and 45 kV distribution voltage and a rarer 30 kV transmission voltage has been introduced especially in wind farm networks for higher power transmission capacity. As stated before, thermal loading capacity sets boundaries for maximum ampacity. However, capacity can be increased by choosing higher voltage level [1]. Table 3. Demonstrates how supply voltage affects the theoretical maximum capacity. Losses and length of the line has not been taken into count.

Table 3. Increase in capacity when voltage is increased.

Voltage [*U*]	Current [*I*]	Power [*S*]
10 kV	435 A	7.53 MVA
20 kV		15.07 MVA
30 kV		22.6 MVA

U = Voltage, *I* = Current, *S* = Apparent Power

While a higher transmission voltage achieves benefits such as lower percentual voltage drop and increase in transmission capacity, it also has negative effects. Generally, higher voltage always requires a higher level of insulation, which increases the costs considerably. As transmission capacity rises, higher amount of power can be transmitted through one line, therefore allowing other transmission connections to be pruned, which could increase interruption costs. [1.]

5 Calculation Parameters

Calculation parameters are listed below and will be used in comparison section of this thesis.

Intrest rate	5%
Increase in annual load	0%
Price of loss energy	0.044 €/kWh = 44 €/MWh
Price of loss power	88 €/kW
Utilization period of losses	2250 h/a
Utilization period of loading	3200 h/a
Duration of calculation period	20 a
Maximum allowed voltage drop	5%
Voltage	30 kV
Repair time	0.77 h
Cost of interruption (a)	1.1 €/kW
Cost of interruption (b)	11 €/kWh

5.1 Voltage Drop

Amplitude of voltage is the most important quality factor from electricity consumers' point of view. Electric device or machine may malfunction if the supplied voltage is too low or too high. In general, the voltage drop becomes more important when approaching the point of consumption of electricity. Stem network transmission lines do not have significant effect on the voltage drop due to automated voltage control equipment. [1, p.38.]

In the calculations of medium voltage network, the most interesting parameter is magnitude of the voltage at terminal point of the line under nominal ampacity [1, p.38].

Phase voltage drop can be calculated from Equation 4

$$U_h = I * (R * cos\varphi + X * sin\varphi) \ , \qquad (1)$$

I is phase current of the load in amperes
R is longitudinal resistance of the conductor in Ω/km
X is longitudinal reactance of the conductor in Ω/km
φ is phase angle

Calculation method given above is valid for short lines; < 100 kilometers with overhead lines and < 20 kilometers with underground cables [3].

Acceptable voltage drop between two terminals of the line is dependent on operating situation and available voltage control reserve. In general, the voltage drop in the medium voltage network is not a factor determining the cross-section of the conductor. However, in case of a failure, the line must be able to transmit power that exceeds the normal level. In such cases, the transfer distance could be very long, and therefore the allowed voltage drop is greater, approximately 8-10% [1.]. Voltage drop becomes problematic especially with long overhead lines in rural areas [2]. Percentual voltage drop of distribution line should not exceed 5% during normal operation [3].

Voltage drop can be mitigated by choosing larger cross-section for the conductor, or by dimensioning the feeding transformer with increased secondary coil turn ratio. Generally, cables have lower voltage drop compared to overhead line, that has equal thermal loading capacity due to larger cross-section. [4, p.305.]

5.2 Power Losses

Evaluation and calculation of losses is an essential part of the design of a medium voltage network. Losses in energy production and transmission are almost entirely the transformation of electrical energy into heat. High levels of losses can cause unwanted temperature rise, which in the worst case can damage the insulation or inflict total breakdown of the conductor due to melting. [1.]

Impedance of the conductor causes power losses. Losses can be divided into active- and reactive losses. The active losses are generated in the longitudinal resistance of the conductor, while the parasitic losses are generated in the longitudinal reactance of the conductor. [1.]

Active power losses in a 3-phase system can be calculated from Equation 2

$$P_h = 3 * R * I^2 \text{ ,} \tag{2}$$

R is resistance of the conductor in Ω/km
I is current of the load in ampere's

Reactive power losses in a 3-phase system can be calculated from Equation 3

$$Q_h = 3 * X * I^2 \ , \tag{3}$$

X is reactance of the conductor in Ω/km
I is parasitic Current of the load in ampere's

5.3 Energy Losses

Calculation of energy losses caused by a conductor is important calculation parameter when total operating expenses are being considered. Firstly, power losses should be calculated at the desired moment of time. Exact evaluation is quite labor-consuming task and therefore approximate calculation method can be used. Approximate value is taken from peak loss power and utilization period of losses. Utilization period of losses is dependent on time dependent loading of the line. The peakier the loading is the shorter the utilization period of losses is. If accurate knowledge of utilization period of losses is not known, 2000-2500 hours per year can be used for medium voltage networks. [1, p.34-35.]

Annual energy losses can be calculated from equation 4.

$$W_h = P_{hmax} * t_h \ , \tag{4}$$

P_{hmax} is peak power losses
t_h is utilization period of losses in hours

Nord Pool offers energy prices day ahead and stores data over the past few years. Day ahead market is useful to define balance between supply and demand. This thesis will use average wholesale electricity price of Finland in 2019, which are listed in Table 4 month by month.

Table 4. Nord Pool wholesale electricity price of Finland in 2019. [8.]

Wholesale electricity price of Finland in 2019	
Month	€/MWh
January	55.8
February	46.8
March	40.0
April	41.4
May	39.8
June	30.7
July	45.9
August	48.8
September	48.8
October	46.3
November	45.7
December	38.4
Average:	44.0

5.4 Economical Calculations

In design phase of medium voltage network, the primary objective is to find solutions that are technically suitable and economically profitable during the life cycle of the line being built. In addition to technical calculations, total life cycle costs for network components and whole medium voltage system should be determined. Costs for components and for the network can be divided into four different groups. Table 5 exemplifies cost groups in terms of fixed, changing, one-off and periodical costs. [1, p.40.]

Table 5. Related costs and characteristics of distribution network [1, p.40].

	Fixed	Changing	One-off	Periodical
Investment	x		x	
Loading losses		x		x
Idle losses	x			x
Interruption costs		x		x
Maintenance	x			x

Different cost groups cannot be directly compared with each other. Comparison can be carried out with two different principles: Either by calculating current value for periodical costs over the whole life cycle, also known as discounting or capitalization, or by changing the investment expenses to periodical annual cost over the entire life cycle, called annuity. [1, p.40.]

Current value can be calculated from equation 5.

$$\text{Current value} = \frac{1}{\alpha^t} = \frac{1}{\left(1+\frac{p}{100}\right)^t}, \tag{5}$$

t is year t in the future
p is interest rate

The calculation of current value will determine the amount of money in which the expense under review can be paid in year t with compound rate. The length of the period and the rate of interest affect the present value of the cost. A high interest rate and a long period decreases the present value and vice versa. [1, p.41.]

Usually, in the context of design tasks, the costs of the entire planning period are calculated and changed to the present value of annual costs. The calculation can be performed by discounting the costs incurred each year to the present. Carrying out the calculation is quite time-consuming, since the planning period is long, approximately 20-40 years, and the assumption is that the load varies from year to year. For this reason, the calculation is carried out in such a way as to assume a constant increase in the load, in which case the present value of the annual cost is calculated by using the capitalization factor. [1, p.41-42.]

Capitalization factor κ can be calculated from equation 6.

$$\kappa = \Psi * \frac{\Psi^T - 1}{\Psi - 1}, \tag{6}$$

T is time of the entire life cycle in years
and

$$\Psi = \frac{\beta^2}{\alpha} = \frac{\left(1+\frac{r}{100}\right)^2}{1+\frac{p}{100}}, \tag{7}$$

r is rise in the annual load in percent
p is intrest-rate

Given equations can be used to calculate current value of loading losses. During design phase, current value of idling losses and interruption costs are calculated by using Equations 5 and 6, however idling losses are always constant and therefore rise in annual load is 0%. Interruption costs are always directly proportional to increase of annual load and therefore Equation 6 needs to modified so that square of the numerator is left out of the equation. [1, p.42.]

One-time cost with long-term impact e.g. investment cost can be turned into an annual cost by calculating annuity from equation seven. [1, p.43.]

$$\varepsilon = \frac{p/100}{1-\frac{1}{\left(1+\frac{p}{100}\right)^t}}, \tag{8}$$

p is intrest-rate
t is consideration time of the investment

In practice, annuity is an equal sized annual cost, which is needed to amortize the capital, and to pay annual interest during the hold time. Annual cost of the investment can be used to compare cost-effectiveness of different line options. [1, p.43.]

5.5 Reliability Calculations

When the reliability of the electricity transmission system is considered, medium voltage lines are usually the point of interest. Approximately 90% of the interruptions in the network are from medium voltage line faults. When total expenses are considered, interruption costs must be taken into count. Interruption costs could end up being deciding factor when profitability of the line to be built is considered. Expense of the interruption could be significant if the end customer experiences e.g. a production interruption. [1, p.44.]

Reliability is divided to different sections and terms;

- Operational reliability
- Fault
- Switching time
- Repair time
- Fail frequency

Annual interruption costs are calculated from annual energy according to maximum active power and utilization period.

$$P_{load} = \frac{P_{MAX} * t_k}{8760} , \qquad (9)$$

P_{max} is maximum power of the line
t_k is the utilization period

After the annual loading power is calculated, the annual interruption cost can be calculated from the following equation 10 [9].

$$K_{k1} = f * l * P_{load} * (a + b * t) , \qquad (10)$$

f is failure density of the line
l is length of the line
a is cost of the interruption in €/kW
b is cost of the interruption in €/kWh
t is repair time of the line in hours

Parameters for failure density are taken from interruption statistics of 2018, issued by Energy authority [17]. Interruptions are given in failure density/100 km. In this thesis, the length of the line is 20 kilometers and therefore the interruption parameters need to be divided by five:

- Interruption parameter for FCCS: 1.504 faults in the length 20 kilometers
- Interruption parameter for underground cable: 0.886 faults in the length of 20 kilometers
  [17, p.15.]

In addition to interruption costs, continuity of electric supply is measured internationally based on standard IEEE 1366 parameters. However, these parameters are not calculated in this thesis [1, p.45].

- System Average Interruption Frequency Index (SAIFI)
- Customer Average Interruption Duration Index (CAIDI)
- System Average Interruption Duration Index (SAIDI)
- Momentary Average Interruption Frequency Index (MAIFI)
  [1, p.45.]

6 System Stability

The power grid with its equipment is a nonlinear and dynamic system in which loads, production and transmission equipment are constantly changing. In a stable power system, synchronous generators keep pace, network voltage and frequency at an acceptable level, despite of changes and failures in the network. [6, p.216.]

6.1 Reactive Power

Power transmission- and distribution grid is a system, where generators produce energy, which is then delivered to end customer through transmission and distribution lines. Due to the nature of alternating current, the system produces reactive power in its transverse reactance, better known as capacitive reactance, and consumes it in its longitudinal reactance, known as inductive reactance. Reactive power is imaginary part of apparent power and it cannot be utilized in doing work as it only bounces back and forth between the supply and the load. However, motors and transformers need reactive power in excitation of windings. If the load is purely reactive, voltage and current tend to be 90° out of phase with each other. Typical sources of reactive power are capacitors and underground cables. Consumers of reactive power are electrical motors, transformers, conductors, and in general devices equipped with coils.

Reactive power plays key factor in system stability since reactive power is directly proportional to voltage. Distribution lines share the same characteristics as power transmission lines. During low load situation, due to conductor's capacitive nature, it produces reactive power and during high load situation, it consumes more reactive power than it produces in its operating capacitances. Conductors' capacitive charging current increases receiving-end voltage of idling- or open-circuit conductor. Such phenomena is known as Ferranti effect. [2.]

Cable produces reactive power in its transverse capacitance since the cable construction is very similar to a capacitor, and in fact, cables can be imagined as a massive capacitor. The produced reactive power can be calculated from equation 8.

$$Q_c = B * U^2 \quad (8)$$

B is ωC
ω is $2\pi f$
f is 50 Hz
C is capacitance in farads
U is mains voltage in volts

Overvoltage caused by capacitive charging current does not significantly concern medium voltage overhead lines. However underground cable systems are, since cables have significantly higher capacitance and therefore, higher charging current [2].

6.2 Voltage Control

Voltage regulation is executed by installing compensation capacitors or shunt reactors either in parallel, or in series with the line, depending on the nature of the load and operating situation. Reactor compensates capacitive reactive power and capacitor compensates inductive reactive power. Some transformers are also equipped with tap-changers. Distribution network holders have device specific compensation units, which are either adjustable or fixed. Series capacitors are also used to compensate voltage drop at receiving end of the line [2.]. Generally, compensation units should be located close to desired compensation destination, since transmitting reactive power limits the active power transmission capacity.

6.2.1 Series Compensation

Series compensation decreases impedance of line and compensates voltage drop caused by reactive power on that part of the line, which is after the compensation unit. This results in lower parasitic current, higher transmission capacity and reduction of voltage fluctuation. Series compensation is usually used with long distribution lines to compensate voltage drop at receiving end caused by conductor's impedance. [2. 10.]

6.2.2 Parallel Compensation

Compensation capacitor installed in parallel with distribution line has different effect compared to series compensation. Capacitor bank installed in parallel with the line compensates both the reactive power of line and load, whereas compensation unit installed in series compensates only that part of the line, which is after the compensation unit. Devices connected in parallel with the line are not affected by short-circuit currents. [2. 10.]

Figure 9 clarifies the differences between series- and parallel compensation.

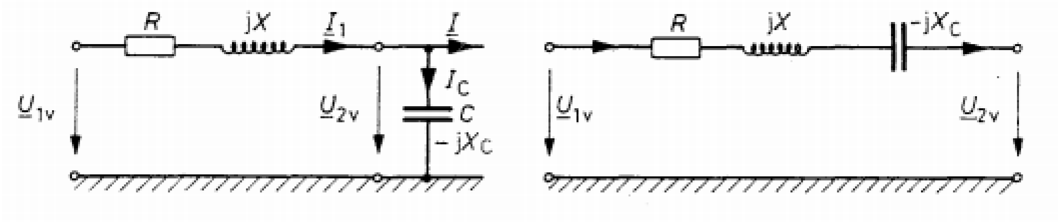

Figure 9. Compensation unit connected in parallel (left), and in series (right) [2, p.10].

6.2.3 Transformer Tap-changer

Transformers can regulate voltage with on-load or off-load tap-changers. On-load tap-changers are more practical because transformers transformation ratio is possible to change under load, yet usually only large transformers are equipped with such device. Off-load tap-changer, however demands disconnection from the grid to adjust the transformation ratio. Tap-changers are connected to primary winding and alters the turns of the winding. Conventional range of adjustment is ± 15%. [4, p.146.]

7 Investment and Construction Costs

This paragraph discusses the costs of a medium voltage transmission line in perspective of investments and construction. The costs associated with the protection of the lines, e.g. relays and disconnectors are not considered, since they can be assumed the same with FCCS line as well as underground cable solution.

An electricity distribution system is a complex system consisting of many different com-components and costs. Mainly, the costs can be divided into four parts: Investment, building, maintenance and operating costs. At the design stage, the most economical products that meet both technical and safety-related boundary conditions should be selected. The dimensioning of the line being built should be done so that the line remains operational for decades, without the need for greater additional investment. Individual medium voltage distribution lines are usually constructed and operated radially. However, the network is looped in order to recover from fault situations by using backup connections.

7.1 Investment and Construction Costs

Investment and construction costs consist largely of selected components and construction location. The geographical location of the line being built greatly influences the choice of the type of the line. In a densely populated area, underground cable is the only option because overhead line simply needs more space than what is available. However, overhead lines are still predominantly used in dispersed settlement areas since cabling is many times more expensive and time consuming than building an overhead line.

In 2013, the Parliament of Finland decided that the reliability of supply of electricity in Finland should be improved. No continuous interruptions of more than six hours shall occur within the station formula area. In other areas, the limit for continuous interruption is 36 hours [7]. Therefore, underground cabling and use of fully covered conductors has been increased in dispersed settlement areas due to their reliability.

Underground cable line investment and construction costs consist almost entirely of the conductor itself and digging of the cable trench. In certain situations, the digging can be more expensive than the cable itself. Cost of the digging depends entirely on the location and soil. The price varies from 11 000€/km (easy conditions) to 150 000€/km (extremely hard conditions) per kilometer. Construction prices related with the FCCS line depend on the pole height and strength. In addition, cross-section has significant effect on the conductor fastening process since bigger cross section adds weight. As stated before FCCS line should equipped with current limiting devices and this factor also increases the construction costs. Approximation for the FCCS line construction cost is 8000 €/km [20.]. As stated before, digging in residential area is significantly more expensive than compared to rural area. Terminations and joints of ground cable are more expensive than similar products for FCCS lines due to their technical requirements and complexity.

7.2 Hold Time

The technical hold time of the components of the distribution network is usually much longer compared to the technical and economic hold time. The reason for this is for example location of the line and use of less popular components depending on the voltage level. In developing regions, technical and economic hold periods are shorter due to an increase in the annual loading and, therefore, the lines may have to be strengthened well before the end of the technical hold period. [1.]

8 Comparison Lines

Following calculation parameters will be used for both lines;

- Capitalization factor: for losses: 12.4527
- Capitalization factor for interruption costs: 12.4179
- Annuity: 0.0802

Parameters were calculated with given example equations from chapter 5.3. Prices for loss power and energy, and calculation period are given at the beginning chapter five.

Product related prices of the thesis research are given in €/km, since exact prices of used products are considered as business secrets. For comparison purposes voltage drop and power losses have been calculated for all AHXAMK-W 18/30(36) kV cable cross-sections in Tables 6, 7, 8 and 9. Technical data of the conductors has been taken from appendices 1 and 2.

Voltage drop is quite significant factor limiting the ampacity of both lines. Maximum ampacity, which complies with the allowed voltage drop, was iterated for both lines and the results were 215 A for FCCS and 430 A for underground cable.

Table 6. Voltage drop with nominal current of the conductor.

Voltage Drop with Nominal Current							
Cable	I [A]	R [Ω/km]	X [Ω/km]	Cos φ	Sin φ	U_h 1-phase [V]	U_h 1-phase [%]
AHXAMK-W 1x300	435	0.119	0.1068	0.95	0.31	1271.57	7.34
AHXAMK-W 1x400	510	0.094	0.1036	0.95	0.31	1238.44	7.15
AHXAMK-W 1x500	570	0.073	0.1005	0.95	0.31	1145.76	6.62
AHXAMK-W 1x630	635	0.057	0.0973	0.95	0.31	1070.78	6.18
AHXAMK-W 1x800	695	0.045	0.0942	0.95	0.31	1000.13	5.77
AHXAMK-W 1x1000	760	0.041	0.0911	0.95	0.31	1021.30	5.90
CCSX 1x241 33 kV	423	0.132	0.2427	0.95	0.31	1697.39	9.80

U_v = 17.3 kV, s = 20 km

Table 7. Voltage drop with equal thermal loading capacity of the conductor.

Voltage Drop with Equal Thermal Loading Capacity							
Cable	I [A]	R [Ω/km]	X [Ω/km]	Cos φ	Sin φ	U_h 1-phase [V]	U_h 1-phase [%]
AHXAMK-W 1x300	430	0.119	0.1068	0.95	0.31	1256.96	7.26
AHXAMK-W 1x400	430	0.094	0.1036	0.95	0.31	1044.18	6.03
AHXAMK-W 1x500	**430**	**0.073**	**0.1005**	**0.95**	**0.31**	**864.34**	**4.99**
AHXAMK-W 1x630	430	0.057	0.0973	0.95	0.31	725.09	4.19
AHXAMK-W 1x800	430	0.045	0.0942	0.95	0.31	618.79	3.57
AHXAMK-W 1x1000	430	0.041	0.0911	0.95	0.31	577.84	3.34
CCSX 1x241 33 kV	**215**	**0.132**	**0.2427**	**0.95**	**0.31**	**862.74**	**4.98**

U_v = 17.3 kV, s = 20 km

Table 8. Power losses with nominal current of the conductor.

Power Losses with Nominal Current					
Cable	I [A]	R [Ω/km]	X [Ω/km]	P_h [MW]	Q_h [MVar]
AHXAMK-W 1x300	435	0.119	0.1068	1.351	0.376
AHXAMK-W 1x400	510	0.094	0.1036	1.467	0.501
AHXAMK-W 1x500	570	0.073	0.1005	1.423	0.607
AHXAMK-W 1x630	635	0.057	0.0973	1.379	0.730
AHXAMK-W 1x800	695	0.045	0.0942	1.304	0.846
AHXAMK-W 1x1000	760	0.041	0.0911	1.421	0.979
CCSX 1x241 33 kV	423	0.132	0.2427	1.417	0.808

Table 9. Power losses with equal thermal loading capacity of the conductor.

Power Losses with Equal Thermal Loading Capacity					
Cable	I [A]	R [Ω/km]	X [Ω/km]	P_h [MW]	Q_h [MVar]
AHXAMK-W 1x300	430	0.119	0.1068	1.320	0.367
AHXAMK-W 1x400	430	0.094	0.1036	1.043	0.356
AHXAMK-W 1x500	**430**	**0.073**	**0.1005**	**0.810**	**0.346**
AHXAMK-W 1x630	430	0.057	0.0973	0.632	0.335
AHXAMK-W 1x800	430	0.045	0.0942	0.499	0.324
AHXAMK-W 1x1000	430	0.041	0.0911	0.455	0.313
CCSX 1x241 33 kV	**215**	**0.132**	**0.2427**	**0.366**	**0.209**

8.1 Underground Cable

Underground cable line for the comparison is carried out as a single three-phase line with AHXAMK-W 18/30(36) kV 1x500 mm^2 cable produced by Reka. Joints and terminations are designed and produced by Ensto.

Used components for the underground cable example:

- Cable joint (CJWH11.4205C)
- Cable termination (COT1.4205L)
- Cable (AHXAMK-W 1x500 mm^2 18/30 (36) kV)

Costs:

Digging difficulty of the cable trench is massive factor for construction costs of an underground cable line. Therefore, construction costs are calculated for all environmental condition classes. Class 1 is for easy conditions and the price is 10,700 €/km. Class 2 is for normal conditions and the price is 24,200 €/km. Class 3 is for difficult conditions and the price is 77,200 €/km. Class 4 is for extremely difficult conditions and the price is 151,200 €/km.

- Total investment and construction costs including shunt reactors and cable trench for single underground cable line; Class 1; 1,070,200€ (53,510 €/km), Class 2; 1,340,200€ (67 010 €/km), Class 3; 2,400,200€ (120,010 €/km), Class 4; 3,880,200€ (194,010 €/km).
- Annuity for the investment: Class 1; 85,900 €/a, Class 2; 107,500 €/a, Class 3; 192,600 €/a, Class 4; 311,400 €/a
- Cost of Interruptions: 65,700 €/a
- Total cost of interruptions discounted for the whole calculation period: 816,300€
- Cost of power losses: 71,300 €/a
- Cost of energy losses: 80,200 €/a
- Total cost of losses: 151,500 €/a
- Total cost of losses discounted for the whole calculation period: 1,886,210€
- Estimated total life cycle costs: Class 1; 4,420,000€, Class 2; 4,853,000€, Class 3; 6,554,500€, Class 4; 8,929,700€

Theoretical loading capacity according to maximum voltage drop without compensation and losses was calculated and the result was 22.3 MVA. Due to capacitive nature of cables, the line produces 1.7 MVAr of reactive power in length of 20 kilometers. Parallel shunt reactors of 1 MVAr were chosen to compensate the capacitive reactive power. Power losses of the line is 880 kVA. Produced reactive power and power losses limit the active power transmission capacity to 21.4 MVA.

8.2 FCCS

Fully covered conductor line of the comparison is a double-line with CCSX 1x241 mm^2 33 kV AAAC conductor produced by Amokabel. Accessories are designed and produced by Ensto. Few boundary conditions were given for the overhead line; Current limiting devices installed to every fourth pole and span distance between poles is 80 meters. Every third pole is secured to place with stay wires.

Components used in investment calculations:

- Current Limiting Devices (SDI48.535)
- Insulators (SDI84.1M20)
- Cross arms (SH1524.3)
- Tightening cross arm (SH183)
- Conductor joints (CIL110)
- Line termination (SO257S)
- Stay wires (SHS25K.165L)
- Wooden poles
- Conductor (CCSX 1x241 mm^2 33 kV)

Due to length of the line, voltage drop is quite significant ampacity limitation factor. Ampacity for FCCS-system is 215 A which is only approximately half of the nominal thermal capacity. If current does not exceed 215 A, the FCCS-line does not need voltage drop compensation.

Costs:

- Total investment price for double FCCS-line is €988,000, which is 49,400 €/km.
- Annuity for the investment: 79,284 €/a
- Cost of Interruptions: 111,600 €/a
- Total cost of interruptions discounted for the whole calculation period: €1,385,500
- Cost of power losses: 64,400 €/a
- Cost of energy losses: 72,500 €/a
- Total cost of losses: 136,900 €/a
- Total cost of losses discounted for the whole calculation period: €1 704 600
- Estimated life cycle total cost: €4,675,000

Theoretical loading capacity according to maximum voltage drop without compensation and losses was calculated and the result was 11.2 MVA. However, covered conductor system is implemented as a double line and therefore the maximum loading capacity is 2 * 11.2 MVA, which results approximately in 22.4 MVA. Power losses of single FCCS-line in the length of 20 kilometers is 420 kVA. Total losses are 840 kVA, which limits the power transmission capacity to 21.6 MVA.

9 Comparison

Comparison of ground cable and overhead line is not unequivocal. The large investment price of the cable and the cable trench of a cable line can multiply the price of a ground cable line compared to a FCCS line capable of transmitting the same amount of power. Although the terminations and joints of the ground cable line are significantly more expensive than the accessories of the FCCS line, the price is quite marginal in terms of overall cost. In addition, the less common voltage level of 30 kV affects the price of components and conductors used in an increasing manner.

The main differences between the lines being compared are in interruptions, and investment, and construction costs. The price of interruptions for the FCCS line is approximately €1,400,000, which is about half as much as the equivalent cable line, €820,000. If the comparison line would be bare overhead line, interruption costs would be significantly higher than compared to an underground cable line.

The 30 kV voltage level is mainly used in the transmission and trunk network of wind farms. For this reason, not all investment and construction costs calculated for ground cable are comparable with the FCCS line. The environmental conditions categories one and two were selected for the cable trench excavation: Easy and ordinary conditions since wind farms are usually located outside of the station formula area and thus the excavation of the cable trench cannot be classified as challenging. The cost of investment and construction of the FCCS line is approximately €990,000 and the cost of ground cable lines under categories one and two are €1,070,000 and €1,340,000. Investing and construction costs are approximately €80,000 and €350,000 lower for the FCCS line when compared with underground cable lines class one and class two.

For comparison, cost of losses differs slightly from each other. The ampacity is equal on both lines, although the FCCS line has two phase conductors for each phase and therefore the loading current of each phase conductor is only the half of the equivalent underground cable solution. On a general level, it can be thought that the conductor produces loading loss costs approximately the amount of its purchase price during the life cycle. However, it should be remembered that the estimation is not very accurate and it can have a margin of error up to 20% [18]. The less common voltage level of components affects the investment price in an increasing manner and therefore the above-mentioned comparison of losses and procurement price of the conductor is not possible to apply within the thesis.

Discounted life cycle cost of losses for the FCCS line is approximately €1,705,000 and €1,890,000 for the underground cable solution. Higher cost of losses for the underground cable line is simply due to higher phase conductor loading current since underground solution has only one conductor per phase. Higher loading current causes more heat losses in accordance with the Ohm’s law, although the resistance of the underground cable line per kilometer is half less than the covered conductor that has equal nominal thermal loading current.

In terms of technical parameters, comparison is quite simple. As ampacity and transmission voltage are the same, the both lines should be able to transmit the same amount of power in theory. However, losses are usually significant factor in decreasing the transmission capacity. Voltage drop for both lines is equal, approximately 5%. Voltage drop is the most significant factor in limiting maximum ampacity in addition to nominal thermal loading capacity. Equal ampacity of both comparison lines means that apparent loading losses are approximately on the same magnitude. As stated above underground cable has higher losses due to ohm's law, since more current per phase conductor is pushed through. Loading losses for FCCS were 840 kVA and 880 kVA for underground cable solution. The most relevant difference between FCCS and underground cable solution in terms of technical parameters is produced reactive power. Since cables are constructed in a way where core conductor and metallic screen form a capacitor-like element, the produced reactive power is much greater than a traditional overhead or FCCS line, since the electrode distance is much smaller. Capacitive reactive power is quite problematic factor in underground cable networks as it causes additional loading on the line and increases line-voltage during low loading situations. Produced reactive power is quite insignificant for FCCS line and it was not calculated. However the underground cable produces approximately 1.7 MVArs of reactive power and the parallel shunt reactors were chosen to compensate the reactive power.

All in all the results for the comparison are surprisingly close to each other. Power transmission capacity is 21.6 MVA for FCCS and 21.4 MVA for underground cable solution. Estimated total life cycle costs are on similar level as well. The main factor that significantly increases the investment cost of underground cable line is the cost of cable trench. Total life cycle costs for FCCS line and underground cable solution Class 1: Class 1 is approximately 255,000€ cheaper than the FCCS line. Class 2 however, is €178,000 more expensive than the FCCS line. Class 3 and Class 4 are not comparable, unless underground cable would be the only option.

Comparison proves that both line-types are quite similar in terms of costs and technical parameters. FCCS double-line has slightly higher power transmission capacity, approximately 200 kVA. Underground cable solution has higher power losses, but lower interruption costs. FCCS-line has lower power losses, but higher interruption costs and therefore life cycle related costs are quite similar. Investment price of FCCS line is slightly less than underground cable solution, approximately €70,000 compared to Class 1 and €340,000 compared to Class 2.

Pros and cons of an underground cable line compared to a fully covered conductor line are listed below.

Pros;

- Smaller space requirement
- Smaller disturbances for the environment
- Protection against live parts
- Good short-circuit reduction coefficient, since part of the ground fault current returns to the feeding source
- Lower voltage drop due to larger cross-section compared to overhead line with equal thermal loading capacity
- Greater short-term overloading capacity
- Significantly lower magnetic field strength
- No harmful noise effect of corona discharge
- Enables watershed transmission lines

  [4, p.304-305.]

Cons;

- Slightly higher investment cost
- Worse cooling features
- Worse long-term overloading capacity
- Worse short-circuit current limitation ability due to lower reactance

- High operating capacitance, and therefore long cable connections must be compensated with shunt reactors
- Difficult and time consuming installability
- Hard to locate cable lines, which are in service, without accurate maps
- Longer repair-time and difficult fault localization
- Heats and dries the surrounding land

[4, p.305-306.]

10 Summary

Purpose of the thesis was to produce an economic and technical comparison for Ensto DSO of different line types of a medium voltage network. The thesis compared the 30 kV FCCS double line and ground cable line and the comparison lines used FCCS and ground cable accessories manufactured by Ensto. The subject of the thesis was chosen to establish which of the line types is more profitable in terms of economic and technical calculations.

The work found out that comparison between the FCCS and the underground cable line are not unequivocal, since the lifecycle costs of both lines consist of many different factors including investment, construction and interruption costs and power losses. The absolute strength of the ground cable line is reliable operational capability, but in terms of power losses, it is slightly less cost efficient than the FCCS line. However, the FCCS line is slightly more expensive than the equivalent underground cable line in terms of interruption costs. A bare open wire interruption costs would be approximately three times greater than the FCCS line interruption costs stated in the calculations and therefore, the higher purchase price of the FCCS line can be justified by lower interruption costs. The difference in life cycle costs was quite small. Comparing the Underground cable Class 1 and FCCS line the life cycle costs of the FCCS line were slightly higher, approximately €255,000, while the cost of Class 2 was approximately €178,000 more. In terms of loadability, the FCCS line was slightly more viable than the ground cable line, at about 200 kVA. As the result of the comparison, the Class 1 underground cable line may be considered as more profitable alternative than the FCCS line. However, if cable environmental Class 2 would be chosen, then the FCCS line would be more profitable.

The results of the comparison depend heavily on the calculation parameters used and the purchase prices of components. As further development phase of the thesis, calculation parameters used in distribution system operating companies should be used in the calculations, e.g. interest rates and peak loading times as they are in the key part of the results. The work presents the necessary calculation methods and replacement of the parameters is after all a quick action.

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AHXAMK-W 18/30 (36) kV- Datasheet

REKA CABLES

TECHNICAL SPECIFICATION

AHXAMK-W
18/30(36) kV

5.6.2017 LaVa

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Technical information	1x300	1x400	1x500	1x630	1x800	1x1000
Product code	1187090	1187091	1187093	1186015	1186013	1186011
Nominal diameter of phase conductor (mm)	20,3	22,5	25,7	29,4	33,3	37,8
Nominal thickness of insulation (mm)	8,0	8,0	8,0	8,0	8,0	8,0
Nominal thickness of sheath (mm)	2,4	2,5	2,6	2,7	2,8	3,0
Nominal diameter over insulation (mm)	35,9	38,1	41,3	45,0	48,9	55,0
Nominal diameter of complete cable (mm)¹	45	47	49	54	58	63
Weight of cable (kg/km)¹	1980	2250	2650	3250	3950	4750
Maximum forces during installation when pulling by						
- Pulling-eye (kN)	15	20	20	20	20	20
- Pulling-stocking (kN)	4,5	6,5	7,5	8,5	8,5	8,5
Minimum bending radii						
- During handling and installation (m)	0,68	0,71	0,74	0,81	0,87	0,95
- In case of only one single smooth bending to final position (m)	0,50	0,52	0,54	0,60	0,64	0,69
Max. d.c-resistance at 20 °C						
- Phase conductor (Ω/km)	0,100	0,0778	0,0605	0,0469	0,0367	0,0291
AC-resistance of phase conductor, screen circuit closed 1)						
- Conductor temperature 65 °C (Ω/km)	0,119	0,094	0,073	0,057	0,045	0,041
- Conductor temperature 90 °C (Ω/km)	0,129	0,101	0,079	0,062	0,049	0,039
Inductance per phase in trefoil formation (mH/km)¹	0,34	0,33	0,32	0,31	0,30	0,29
Capacitance (µF/km)¹	0,24	0,26	0,30	0,32	0,35	0,41
Charging current (A/km)²	1,3	1,4	1,6	1,7	1,9	2,2
Earth fault current (A/km)¹	3,9	4,2	4,9	5,2	5,8	6,7
Current ratings in trefoil (according to CENELEC HD 620 S2 2010 Part 10F) when screen circuit is closed						
- Cables in air (25 °C), conductor temperature 90 °C (A)	565	680	775	880	1010	1130
- Cables in ground (15 °C and 1,0 Km/W) installation depth 0,7 m, conductor temperature 65 °C (A)	435	510	570	635	695	760
Maximum 1 second thermal short-circuit current						
- Phase conductor (temp. at the beginning 90 °C, final temperature 250 °C) (kA)	28,3	37,8	47,2	59,5	75,6	94,5
- Metallic screen (temp. at the beginning 85 °C, final temperature 250 °C) (kA)	5,6	6,0	6,4	6,9	7,5	8,4

1) Calculated value, for guidance only
2) Calculated value for guidance, with operational voltage U = 30 kV

CCSX 1x241 AL7 33 kV W- Datasheet

CCSX 241 AL7 33kV W - Hybrid

Conductor, AAAC

Longitudinal water blocked by extruded filler

Extruded, inner semiconductive layer

Insulation of XLPE

Outer layer of UV-resistant HDPE

Conductor and all layers simultaneously manufactured in one operation EN50397-1

Crossection	**241**	[mm²]
Lay up of conductor	19x4,02	[-]
Conductor diameter, bare conductor, nom	20,1	[mm]
Inner semi conductive layer, thickness, nom	0,3	[mm]
Inner XLPE covering, thickness, nom	2,43	[mm]
Outer UV-resist. HDPE-covering, thickness, nom	1,2	[mm]
Diameter over covering, nom.	27,4-29,0	[mm]
Weight, nom	1023	[kg/km]
Rated operating voltage U	33	[kV]
DC-resistance at 20°C, maximum	0,132	[Ohm/km]
Resistance temp. coefficient	0,004	[/°C]
Lightening impulse withstand strength of XLPE	100	[kV]
Operating temperature, maximum	80[1]	[°C]
Max load(IEC 61597), cond.temp 80 °C, air temp. 40°C, wind speed 0,5 m/s, Solarradiation 1200W/m², α=0,9, ε=0,15 approximate value	423	[A]
Max short circuit current, 1 sec ΔT: 80-250°C	24,1	[kA]
Tensile strength of conductor, calculated	61,5	[kN]
Color	Gray	[-]
Aluminium alloy	AL7	[-]

All illustrations and specifications of weights, size and dimensions are indicative only

(1) 80°C is recommended minimize the risk of mechanical slippage