KARELIA UNIVERSITY OF APPLIED SCIENCES
Degree Programme in Electrical Engineering

Heikki Vinni

Remote Sensing of Medium Voltage Grid: Case Elenia

Thesis
May 2013

THESIS
May 2013
Degree Programme in Electrical Engineering
Karjalankatu 3
FIN 80200 JOENSUU

Author(s)
Heikki Vinni

Title
Medium Voltage Grid Remote Sensing: Case Elenia

Commissioned by
Arbonaut Oy

Abstract

Arbonaut offers several remote sensing services for electric and forest companies alike. As most of their power line analyses are done for the United States of America, they vary greatly in the detail, accuracy and means with what is those in Finland. The purpose of my thesis was to study which methods Elenia currently uses for aerial inspection, what the level of automation is in the process and how Arbonaut could further develop services to have them put to use domestically.

This thesis will not go into great detail about remote sensing technology as previous studies of such already exist in the company. I have prior experience inspecting high voltage transmission lines from a previous employment at Eltel Networks Oy. In order to learn more about distribution lines and their inspections as well as aerial inspection in general and the equipment used in it I interviewed the foremen at Arbonaut Ltd and Elenia Oy's grid maintenance.

Language	Pages
English	Appendices

Electricity distribution, remote sensing, laser scanning, medium voltage network

Karelia AMMATTIKORKEAKOULU	**OPINNÄYTETYÖ** **Toukokuu 2013** **Sähkötekniikan koulutusohjelma** Karjalankatu 3 80200 JOENSUU
Tekijä Heikki Vinni	
Nimeke Keskijänniteverkon lentotarkastuspalvelut: Case Elenia Toimeksiantaja Arbonaut Oy	

Tiivistelmä

Opinnäytetyön tarkoituksena oli selvittää Elenian tarpeita keskijänniteverkon johtokatujen lentotarkastuspalveluista. Koska samasta aiheesta Arbonautille on tehty opinnäytetyö jo vuonna 2010, verrattiin tarpeita aiempiin sekä Arbonautin tällä hetkellä tarjoamiin valmiisiin tuotteisiin. Tarkastustekniikkoina olivat linja-alueen laserkeilaus, 3D-kuvaus sekä valokuvaaminen eri kameratyypeillä. Koska suurin osa Arbonautin asiakkaista ovat Yhdysvalloista, ei valmista tuotetta oltu vielä kehitetty Suomen markkinoille. Lentotarkastuspalveluista LiDAR-tekniikalla kerätys laserkeilausdatan käsittelyyn ja automaattiseen analysointiin Arbonaut on aloittanut tuotekehityksen jo vuosia sitten, mutta komponenttitarkastukseen ei löydy vielä pätevää henkilökuntaa.

Opinnäytetyö esittelee keskijänniteverkon komponentit johtokäytävällä sekä kuvaa lyhyesti johtoalueen kasvillisuusrajoitteita. Työ kuitenkin keskittyy tarkemmin komponenttipuoleen, koska kasvillisuustekijöistä on aiempaa tutkimustietoa sekä opinnäytetöitä. Oma tutustumiseni aiheeseen alkoi vuonna 2011 kun Arbonaut rekrytoi sähkötekniikan insinööriopiskelijoita koulustamme. Koska opetuksemme ei sisällä lainkaan tietoa tarkastuksesta, eikä juurikaan verkon komponenteista, on tietoa tullut hakea itsenäisesti ulkopuolisista lähteistä. Sähköverkkojen analysoinnista laserkuvatun datan pohjalta kokemuksena toimi työni Arbonautilla, kun taas työkokemus Eltel Networks Oy:n siirtoverkkoasentajana toi käytännön osaamista sekä tuntemusta linjarakenteista.

Kieli englanti	Sivuja 38

Asiasanat
Sähkönjakeluverkko, lentotarkastus, keskijänniteverkko

Acknowledgement

This thesis was written in Spring 2013 during my final year of Electrical Engineering studies at Karelia University of Applied Sciences.

I would like to take this opportunity to gratefully acknowledge the expertise, assistance and contributions of those who helped me in this undertaking.

Deserving of special mention are Arbonaut’s Tuomo Kauranne and Jari Kinnunen for providing an interesting subject.

I wish to acknowledge the help provided by Elenia's maintenance engineer Jukka Rajala who showed interest in my thesis and allowed me to interview him at length as well as shared his experiences regarding inspections.

I extend my thanks also to my teachers Tarmo Makkonen for supervising this thesis and providing me with professional guidance and Liisa Sandvall for much needed help with the language.

And to my parents for the unconditional support throughout my degree.

In addition, a thank you to my colleague Matti Korhonen for his 2010 written thesis on the same theme; it has worked as a great guide and a given me much insight.

Last but not least, to my fiancée Ella. You have helped me in ways I could write a book about, but probably never will. Thank you.

Heikki Kinni

Contents

ABBREVIATIONS

AMKA	Low-voltage aerial bundled cable
CCA	Chromated Copper Arsenate, a no longer allowable wood preservative
DGPS	Differential GPS, an enhanced reference-using GPS
ECW	Enhanced Compression Wavelet, aerial imagery wavelet compression image format
FLIR	Fault detection, Location, Isolation and supply Restoration
GPS	Global Positioning System, a satellite positioning system kartastokoordinaattijärjestelmä
KKJ2	Finnish geographic coordinate system,
KTMp	Decision of the Ministry of Trade and Industry, Kauppa- ja teollisuusministeriön päätös
LiDAR	Light Detection And Ranging, an optical remote sensing technology
MTK	The Central Union of Agricultural Producers and Forest Owners, Maa- ja metsätaloustuottajien Keskusliitto
PAS	A plastic covered overhead conductor without a metal sheath
PEX	Cross-linked polyethylene, a dielectric plastic
SAMKA	A medium-voltage aerial bundled cable

1 Introduction

Because of the harsh winters and long periods of little sunlight the energy demand in Finland is substantial. The all-time peak electricity consumption, slightly below 15 Gigawatts, was recorded in February 2011. When combined with drastically changing seasons, long distances and varying landscapes the national grid needs regular maintenance, updating and inspections. This thesis is written for my employer Arbonaut as an important part of my Bachelor of Engineering studies.

The first objective was to find out Elenia's current power line remote sensing methods and why such are decided to be used. After comparing Elenia's inspection needs to the solutions Arbonaut currently has to offer, it was clear that the current products need development to suit Elenia’s needs.

This thesis explains the medium voltage grid, line area and main components used in electricity distribution. The subject touches vegetation analysis, but does not go into detail as sufficient knowledge of the topic already exists. Inspections are viewed from a component inspection aspect.

2 Finnish electric power system

Electric energy can be either produced domestically or imported from a foreign country. Excluding very remote locations with solar panels and parts of heavy industry, electricity is usually produced off-site. The function of electric power transmission is to transfer electric power from a power plant to a load location reliably and with minimal loss.

The Finnish electric power transmission main grid is administered by Fingrid and consists of 400/220/110kV power lines with the equipment attached to them. The consecutive parts, district grid (110/45kV), substations (110/20kV and 45/20kV), medium voltage grid (20kV), distribution transformers and low voltage network (0.4kV) belong to and are administered by the local electric companies. This whole large network is a part of a synchronous inter-Nordic system, which unites the transmission grids in Sweden, Eastern Denmark and Norway. There are also high-voltage DC connections to Estonia and Russia. /1/

Household customers are always connected to the distribution grid which consists of grid parts with voltage of 45kV or less. The distribution grid consists not only of the distribution lines, but also of the connected substations, distribution transformers and local and remote controlled disconnectors. The part of grid where to an industrial customer connects, is case-specific and depends on the customer's power usage.

2.1 Effect of power lines on nature

Following a major enterprise sale completed in January 2012, the electricity distribution and district heating operations formerly provided by Vattenfall have passed to a domestic company Elenia. Operations are now provided through two new companies Elenia Oy and Elenia Lämpö Oy. Elenia operates in one hundred local districts in Central and Western Finland, supplying heating and electric power to 410 000 customers, both homes and businesses.

Elenia is creating a weather and tree proof electrical network by undergrounding. Their objective is to have 70% of their network cabled underground by 2028. The company undertook a large project along with universities, component manufacturers and contractors between 2006 and 2009 to develop solutions improving network reliability. Based on the results a decision was made in 2009 to start undergrounding their whole grid by no longer building overhead power lines. The overhead grid sections requiring renewal would be replaced by buried cables, which would increase the level of undergrounding considerably as seen in TABLE 1. Elenia's annual investments in electrical network and its services in 2013 are 70 million euros. /2/

In addition to undergrounding Elenia has improved crucial components in the networks, such as remote controlled disconnectors, earth fault compensation controllers and circuit breakers. Currently more than 3500 disconnectors and circuit breakers are remote controlled and are of an important role in the automated fault detection, location, isolation and supply restoration system FLIR. /2/

The Janika-storm in 2001 was one of the first occasions where the current weather protection of the nation's electrical grid was proven inadequate. Later the thunderstorms during the summer of 2010 and the Tapani-storm in December 2011 confirmed that service reliability must be improved. Parliament is currently processing an amendment to the Electricity Market act to raise the reliability of electricity supply. As this would require immense investments, the amendment favours undergrounding and will simplify the placement of electrical equipments, especially in road areas.

	2009	2013
Grid Total	62 600km (21 %)	64 300km (25 %)
Medium voltage network	22 600km (7 %)	22 700km (12 %)
Low voltage network	38 900km (29 %)	40 100km (34 %)

TABLE X, Level of network undergrounding in Elenia /2/

As a part of the frontier of technological development much thought is put how to make power lines more ecological. The greatly changing landscape in Finland offers challenges in how and where to build. As Elenia no longer constructs overhead distribution lines, but undergrounds them, much more forest is left for forestry instead of being logged from the right-of-way.

A Ministry of Transport and Communications' work group has drafted a proposal for action concerning blizzard-related outages in December 2012. Very strong wind and unforeseen amounts of snowfall caused extensive and lengthy outages especially in sparsely populated areas and rural communities, both of which largely rely on overhead power lines. The Highways Act (Maantielaki) is proposed to be amended so that the placement of equipment vital for the functioning of the society in road area would become more feasible. The said amendment is meant to promote undergrounding distribution lines roadside, hence increasing their reliability. /3/

When a distribution line is constructed or moved to roadside, trees need to be logged only from one side as the road remains on the other. This saves again not only time but also resources. This would keep the initial costs 30% lower as opposed to constructing elsewhere where all trees would already be logged and possible bedrock lowered. Until recent the Finnish Transport Agency (Liikennevirasto) has opposed installing underground distribution cable in the slope along a road by appealing to safety issues. As the majority of the medium voltage grid built in rural areas uses treated wooden poles to keep the overhead wires in the air, the total amount of poles goes up to hundreds of thousands. A number so great means that the environment must be taken into consideration when choosing the impregnating agent for the wooden poles. The Government Decree (787/2007) based on European Union Commission directive (2006/139/EY) has prohibited the use of chromated copper arsenate, later on CCA, in Finland since 2007. Earlier it had been the most used pole wood impregnant as, unlike creosote, it did not stain or have a strong smell to it. CCA is very toxic and wood treated with it requires special disposal so that arsenic would not be released into the environment. Current substitutes are wood-tar creosote and copper-impregnation. When treated wooden poles are removed from service, be it due to undergrounding or reconstructing, Elenia uses subcontractors to dispose them sustainably.

A power line built on forestland divides properties and occupies a larger area than when built roadside. A common value for the roadside right of way is 7-8 meters, when in a forest the number would be 10 meters. As a result of relocating the power line roadside 25% of the original right of way would be released for forestry. The technical advantage of undergrounding is even far greater. Hence it would be advantageous for the environment to have the overhead power lines relocated and undergrounded roadside.

The renewing of the medium voltage grid, however, is slow and the current overhead power lines will remain in forests for a long time. The total length of medium voltage overhead network in Finland is 119 661 kilometers. According to a recent inventory 67 511 kilometers (56.4%) of the previous number is located on forestland, which leads to an estimate of 67 000 hectares in area. The forestland right of way is a 10 meter wide area which is kept deforested by regular clearing subcontracted by the power line company.

Outside the power line's right of way is the bordering tree line, which is critically important when it comes to the reliability of electricity distribution. Most of the storm and snow related faults are caused by trees outside the right of way touching conductors; either being bent by snow or fallen in a storm. Should the width of the bordering tree line be assumed to be 10 meters on both sides of the right of way; would this lead to an area of between 130 and 140 000 hectares of forestland considered as bordering tree line.

According to Finnish Energy Industries' experience, the appropriate care of bordering tree line is a benefit to both the forest owner and the power line owner. A well-kept bordering tree line increases the reliability of electricity distribution substantially without causing expense or loss to the forest owner. Currently instructions for project planning and execution to optimize the care of the bordering tree line are being compiled. This joint project among the Forestry Development Centre Tapio, electricity companies and the Ministry of Employment and the Economy is due to finish in the end of June 2013. /5/

According to a government proposal, the possessor of the distribution network should in the future be allowed to log and remove trees and other plants in the vicinity of the distribution line area, should it be necessary to stop an outage or to prevent future outages. /6/

2.2 Distribution Grid

In Finland the electrification of rural areas began after the World War II, as in most countries affected by it. The growth of electricity utilization had peaked so the demand was high and on the rise. The first constructed utility poles were not very long-standing since the wood used was not treated with preservatives. Later on more viable solutions were made by using pressure-treated poles, which would significantly outlive their predecessors by repelling insects and fungi.

In distribution grid use Elenia has decided to underground the grid wherever possible when building new or renewing already existing parts of the grid. Undergrounding substantially raises initial costs, but decreases lifetime operational costs as cables are better protected from weather conditions (falling trees or lightnings), thus resulting in fewer faults and outages. Furthermore, underground cables are considered to be much more aesthetic, they require much narrower a right of way, resulting in smaller compensations to landowners as fewer of their trees will be cut down. Other smaller, but noteworthy advantages are fewer restrictions for low flying aircrafts, better protection from sabotage and theft as well as a smaller resultant radiating magnetic field.

Whereas the undergrounded cable seems advantageous compared to its overhead rival, it still has its flaws. Finding a fault from an aerial cable can be as easy as driving along the power line, but finding the same fault underground can take much longer. Excavators and diggers are warned by a near-surface buried warning ribbon but still they tend to damage cables every now and then. Locating and repairing an underground fault can take a very long time so a replacing delivery route for electricity is required. While not very important in Finland, the undergrounded cable is very sensitive to ground-shifting and earthquakes. Also capacity growth must be estimated thoroughly as it is impossible to just change the conductors or uprate the voltage, like one would do with an overhead line. /14/

Electric companies aim to be able to provide their customers with satisfactory quality electricity as cost-efficiently as possible. Companies do not strive to supply customers with highest possible quality as this would require significant additional investments in the grid infrastructure. This remains as something the customers are not willing to see reflected on their electricity bills.

The quality of electricity is affected by:

- outages in the electricity supply
- restrictions in the electricity right of use
- rapid voltage variations
- voltage graph distortions
- rated frequency deviations
- voltage asymmetry /7/

3 Inspection

As this thesis focuses on remote sensing and the inspection of data gathered by earlier mentioned method, the on-site inspections are explained very briefly. Aerial inspections in Finland, including laser scanning, have been used to examine power lines since 2008. So far Elenia has had the majority of its distribution grid inspected from the air. So far the flight service provider has been a Swedish company and the aircraft of choice has been a helicopter with several cameras and a laser scanner attached to its bottom. With both methods, photography and laser scanning, used simultaneously, the width of the laser scanned area remains only a little wider than the right-of-way in order to get the most of the photography equipment. The use of an airplane is not an option because of the poor maneuverability and the high air speed required. /15/

3.1 The basis for inspections

The statutory ground for inspecting electrical network is defined in its possessor's responsibilities written in the decisions of Ministry of Trade and Industry (KTMp 516/96 and 517/96), Law of Electrical Safety (410/96), and Regulation of Electrical Safety (498/96). Thereby the possessor must take care of its electrical equipment in a way they would not pose threat or disturbance and that all faults and defects observed are removed quickly enough. By having their electrical network inspected, the companies also receive important information about the state of their network, thus being able to improve the quality of their electricity distribution. Law of Electrical Safety (410/96) states the following:

2§

This law applies to such devices and equipment that are used in the production, transmission, distribution or use of electricity and the electrical or electromagnetic properties of which can cause danger or disturbance.

5§

Electrical devices and equipment must be designed, built, manufactured and repaired and they must be taken care of and be used so, that:

1) they cause no danger to a person's life, health or assets;
2) they cause no unreasonable electrical or electromagnetic disturbance; and
3) their operation is not easily disturbed electrically or electromagnetically

21§

The Ministry may order certain electrical equipment to be serviced fixed-term and that equipment requiring regular maintenance must have maintenance and service programs drafted in advance.

Periodic inspections (517/96)

12§

Electrical equipment in use must be periodically inspected as follows:

1) class 1 electrical equipment apart from residential building every fifteen years
2) class 2 electrical equipment apart from the network holder's electrical network every ten years
3) class 3 electrical equipment and network holder's electrical network every five years

All of the equipment explained immediately above require a designated Operation Manager who is responsible for the organizing the periodic inspections. The translations above are unofficial. The laws are legally bonding only in Finnish and Swedish. /8, 9, 10, 11/

3.2 Types of inspection

As medium voltage lines are located mostly on forestland and are structurally quite small and simple, live aerial inspection has been deemed uneconomic. When the fact is added that inspection through aerial photographs also leaves a clear record of all electrical equipment and their current state, Elenia has decided to only do the latter. Critical faults noticed inflight are always reported forward immediately so needed measures can be taken as fast as possible. The following chapter explains all inspection methods Elenia currently uses.

3.2.1 Periodic inspection

Maintaining the electrical safety of electrical equipment is its possessor's lawful responsibility. Regulations demand that all electrical equipment is taken care of according to the manuals for operation and maintenance as well as, in some cases, a predetermined maintenance schedule. All equipment must be inspected accordingly after both constructing and reconstructing. Network holder's electrical grid is considered comparable to a class 3 electrical device, so the maximum inspection interval is five years. Elenia has expedited this by inspecting the network every four years. As a walk-through inspection is not mandatory, Elenia has chosen to have the medium voltage grid aerial photographed and inspected from those photographs. This means that once the grid has been flown through, no weather conditions can longer delay the inspections as they are done indoors with a computer. The fact that the actual inspection is not done from a flying helicopter means less distractions, further improving the inspection quality.

Aerial power line inspection in Finland, including laser scanning, has been used since 2008. So far Elenia has had majority of its medium voltage grid inspected from aerial photographs. The flight service provider used has been a Swedish company and the aircraft has been a helicopter with several cameras and a laser scanner attached to its bottom. With both remote sensing methods used simultaneously, the width of the laser scan can only be a little wider than the right-of-way in order to get the most of the photography equipment. The use of an airplane is not an option because of the poor maneuverability and the high air speed required. /2/

Elenia has chosen to use four cameras mounted on the underside of a helicopter; two of which cover a general view of the power line, one facing forward and the other rearward. Two zoom cameras are oriented the same way to take detailed pictures of grid components. The zoom cameras are remote controlled so they can be maneuvered to cover each component. An aircraft flying close to power lines is sure to attract attention so Elenia always informs its customers of future inspections in local newspapers and on their website. Also the grid control room must be informed in case an accident happens. /2/

Another very important aspect in periodical inspection is not only to determine the current status of the structures and the distribution line, but also to evaluate the remaining life time and future changes in its condition. This future planning plays a great role in minimizing maintenance costs. When a fault is recorded as having been repaired, the old data entry must not be erased but be put into historic data. This data can be used later on to evaluate deterioration as well as vegetation growth.

3.2.2 Stereoscopic-imaging

This is a very new inspection method where, instead of one picture, two pictures are taken crosswise from the same subject. These two cameras are synchronized to act as one and the image rendering process is automated. This allows the pictures to be viewed elsewhere with a stereoscopic effect, a feeling of depth. Viewing requires a specific display to be used and often a set of 3D-glasses. The 3d-image cannot be zoomed in, so if more detail is needed the viewer must inspect the additional forward and rearward camera pictures.

Because of the stereoscopic effect, the height of vegetation can be evaluated much more accurately than from a conventional photograph. This could also prove useful when planning pole heights and line locations. Currently Elenia uses this 3D-method mainly to inspect the need for vegetation clearing.

3.2.3 Rot/decay inspection

Elenia makes a rot inspection for a distribution line pole once during the pole's service life. When a pole has been in service for 40 years, the topsoil is removed from the pole's base and the base is checked for rot with a spike and an auger. The result is then transferred to the grid database and compared to a decay model which models the condition of the pole. This estimates the remaining service life and urgency of pole replacement. As this inspection requires an on-site visit the pole is also inspected for any other defects, such as woodpecker holes or ants.

3.2.4 Thermal and corona imaging

Corona is an electrical discharge, caused by the ionization of air surrounding a conductor. Due to the relatively low voltage of a 20kV distribution line, a corona discharge is very rare to encounter. A corona discharge emits ultraviolet light so a special video camera is used. This video is then compared to a regular video in order to find the faulty point.

Though having a multitude of commercial applications (photocopying, air ionizers and deodorizers), corona should not have a place in electric power transmission. It can be caused by broken conductor strands or a faulty insulator. Common problems caused by this phenomenon are audible noise, radio interference and further insulation damage.

Elenia has tried using thermal imaging in distribution line inspections, but it has not proven useful. Sunlight alone can heat the surface of an object, which makes data interpretation more difficult. For best resolution, thermal video should be recorded during winter time, when the consumption of electricity is at its highest and the surroundings are very cold.

3.2.5 Inspection of guy anchor rod corrosion

There are several options available to reduce anchor rod corrosion. In wet or very acidic ground the anchors are encased in concrete. This encasement protects the metal from stray current corrosion by blocking direct anode-cathode contact. Another option is to insulate the guy wires from the anchor by using plastic or ceramic insulators. This also offers a superior protection against lightnings by removing the galvanic connection to the ground through the guy wires.

A loose guy wire can sometimes be spotted from a photograph, but to determine the condition of the anchor some topsoil must be removed. A strong metal anchor can corrode in the course of time so badly that it breaks. This sudden loss of tension can cause the pole to fall over. So far Elenia has not had problems with anchor corrosion so this type of independent inspection is not used.

3.2.6 Grounding inspections

As earthing conductors are underground, the only way to verify their sufficiency and condition is by measuring the earthing impedance. Elenia measures substation and disconnector groundings according to the SFS6001-standard by using a 100 metre fall of potential-test method. These inspections are done in a separate inspection circulation.

3.3 Component inspection

3.3.1 Crossings

All structures that cross a power line must be noted for safety reasons. Such are ditches, roads, railways, water bodies and other power lines. Excavating in or closer than 3 metres from the sides of a power line area is forbidden as pole earthings can be dug to connect with the next pole's earthing. Substations also have a grid earthing electrode surrounding them to further lower the earthing impedance. Some poles also have radial earthings.

3.3.2 Earth conductor and connection

Some poles, due to equipment installed on them or for extra protection, have a grounded cross arm with a ground lead down to earth. For impedance measuring this lead has a bolt joint above the ground. Especially on pastureland this joint must be placed very low or else animals may try to rub themselves against it, damaging the ground lead. This joint can also be broken due to excavating near the pole area or can be damaged because of a passing lightning.

3.3.3 Foundation

The foundation, or pillar, can crack, spall and erode in the course of time. If noticed early, the concrete structure is easy to fix and it can be protected from further damage. Nearby excavations and floods can cause ground movement, resulting in a tilted pole position. The pole can be temporarily straightened with guys, but the foundation still needs to be replaced.

Signs

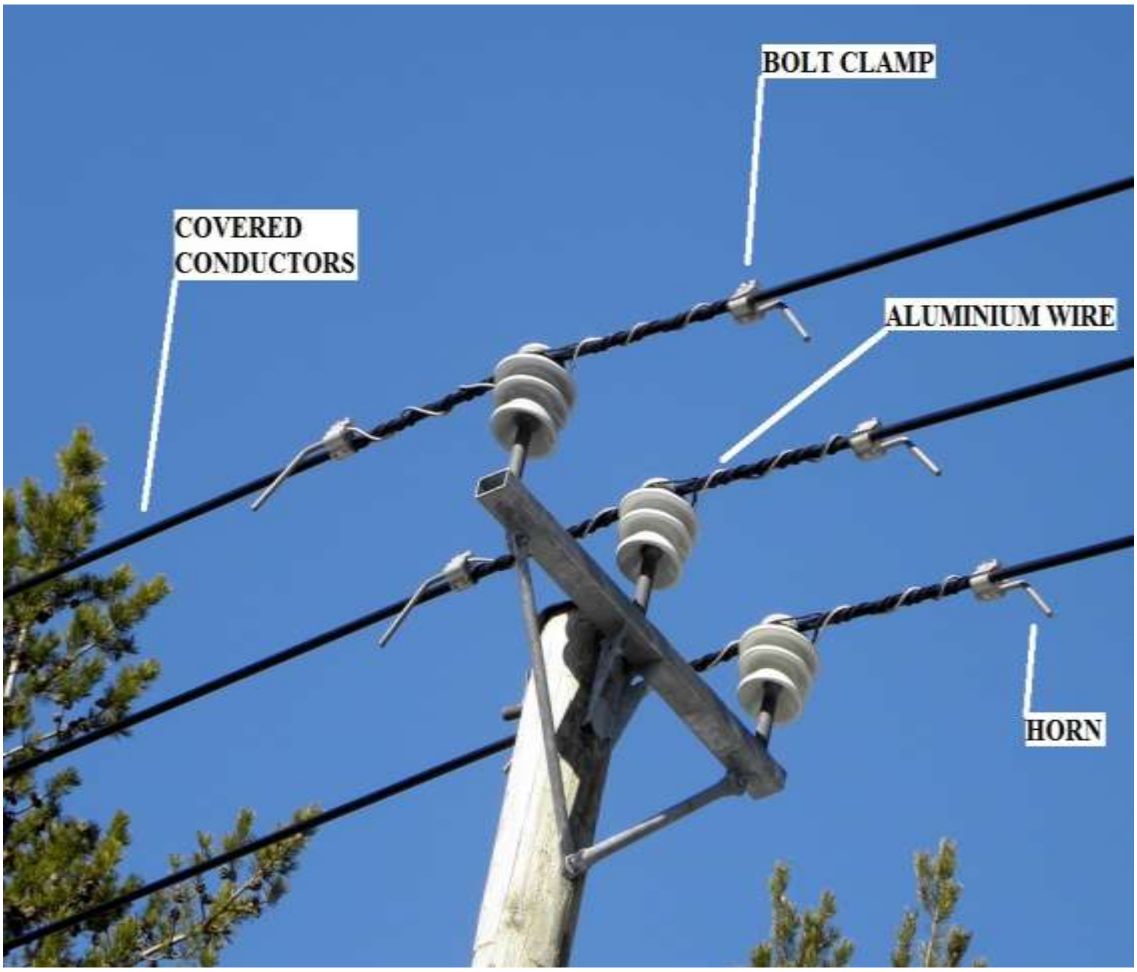
In locations where people or vehicles may pass the guy wires, guy guards must be used. These alternating black and bright yellow plastic tubes are wrapped around guys to make them more visible so they would not pose danger to passers-by. /14/

When a utility pole is shared with other uses, a yellow joint use warning tape must be wrapped around the pole to warn of the high voltage above. A pole may share a 0.4kV AMKA-line, an optical fibre or a telephone line and the service personnel might need to climb on the pole as well. This tape is to warn the personnel not to climb any higher. The lack of the joint use tape is the second most common fault noted in inspections. /2, 14/

A danger to life-sign must be attached to poles which people have direct access to. Such are poles close to roads, paths and population centers. The sign is put on the side from where it is most likely to be seen, which makes the position case-specific. Sunlight will deteriorate the sign over time and they are also considered as collectibles, which makes this the most common fault noted in inspections. All poles in agricultural fields must have danger to life-signs and guy guards as they are frequently passed by vehicles. /2, 14/

3.3.4 Conductors

In a three-phased system the number of conductors is always a multiple of three. Conductors must not have broken strands showing as this will lower the tensile strength as well as cross-section and can cause interference. Stranding however is very rare in medium voltage as the spans are relatively short and as the conductors are not very thick, the stress is also low. Broken strands can be fixed with a repair sleeve. Conductors are supported and held in place by the insulators so the attachments must also be checked. Overvoltages can leave burn marks on the location where the arc was formed.



PICTURE 1. 20kV Arc protection device

Some lines have flash barriers or surge arresters to protect the conductor from lightning-induced arcs and overvoltages. Their condition, position and mounting are important for them to function properly. Picture 1 shows how a two-sided arc protection is installed in a looped grid, whereas in a radial line the protector is only installed on the load side of the insulator. The aluminium wire is wrapped around the insulator neck so that it would guide the formed arc to burn between the two horns of adjacent phases, allowing the substation protection to disconnect the line, quenching the arc. The horns are replaceable and their function is to be worn instead of the actual conductors.

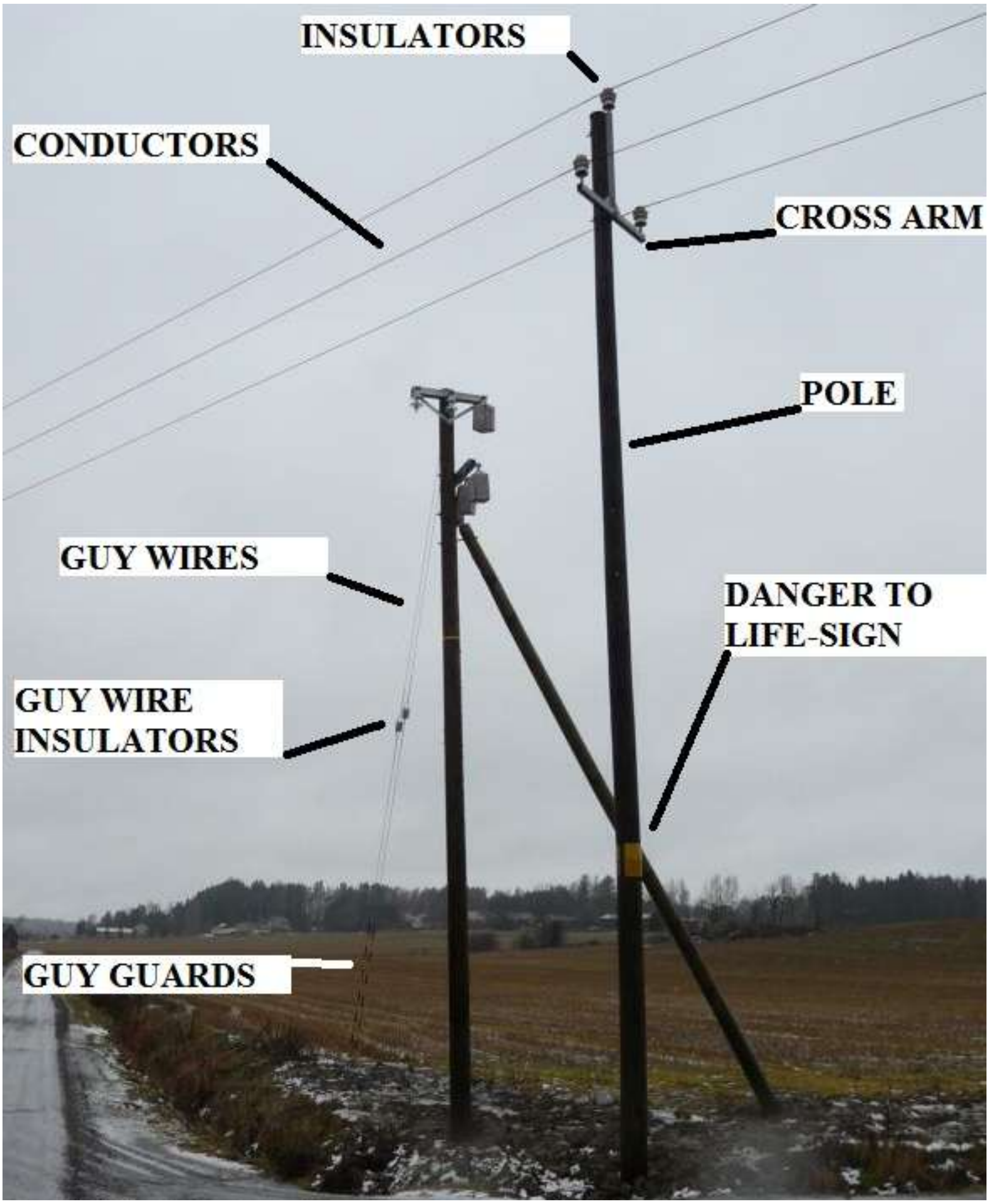
The tightness of the conductors needs to be evaluated as well. All phases should have relatively the same sag on each span, aside from dead-ends and line curves.

3.3.5 Insulators

A conductor is attached to a cross arm via a pin insulator. The insulator is ceramic and the most common colours are white, clear and dark brown. Their function is to prevent a breakthrough through the cross arm to the ground lead and/or other conductors. Melted, chipped and very dirty insulators must be noted as they may not work properly in an overvoltage situation and can pose danger. Bird droppings form a less-insulating layer on top of the ceramic which can cause discharges. In some rare cases the insulators have been used as target practice and are missing fragments or are cracked in half. Insulators cannot be repaired, but must always be replaced instead.

3.3.6 Pole

The most common medium voltage pole material in Finland is impregnated wood. Other materials are composite and steel, with the very rare exception of concrete. Wooden poles need to be checked for rot, which is explained further in chapter 3.2.3. As gravity pulls the impregnating agent downwards, the top of the pole will first become vulnerable to rot. A pole hat protects the pole top butt from absorbing water thus lengthening its service life. Picture 2 shows an example of two pole structure types.



PICTURE 2. 20kV pole structure

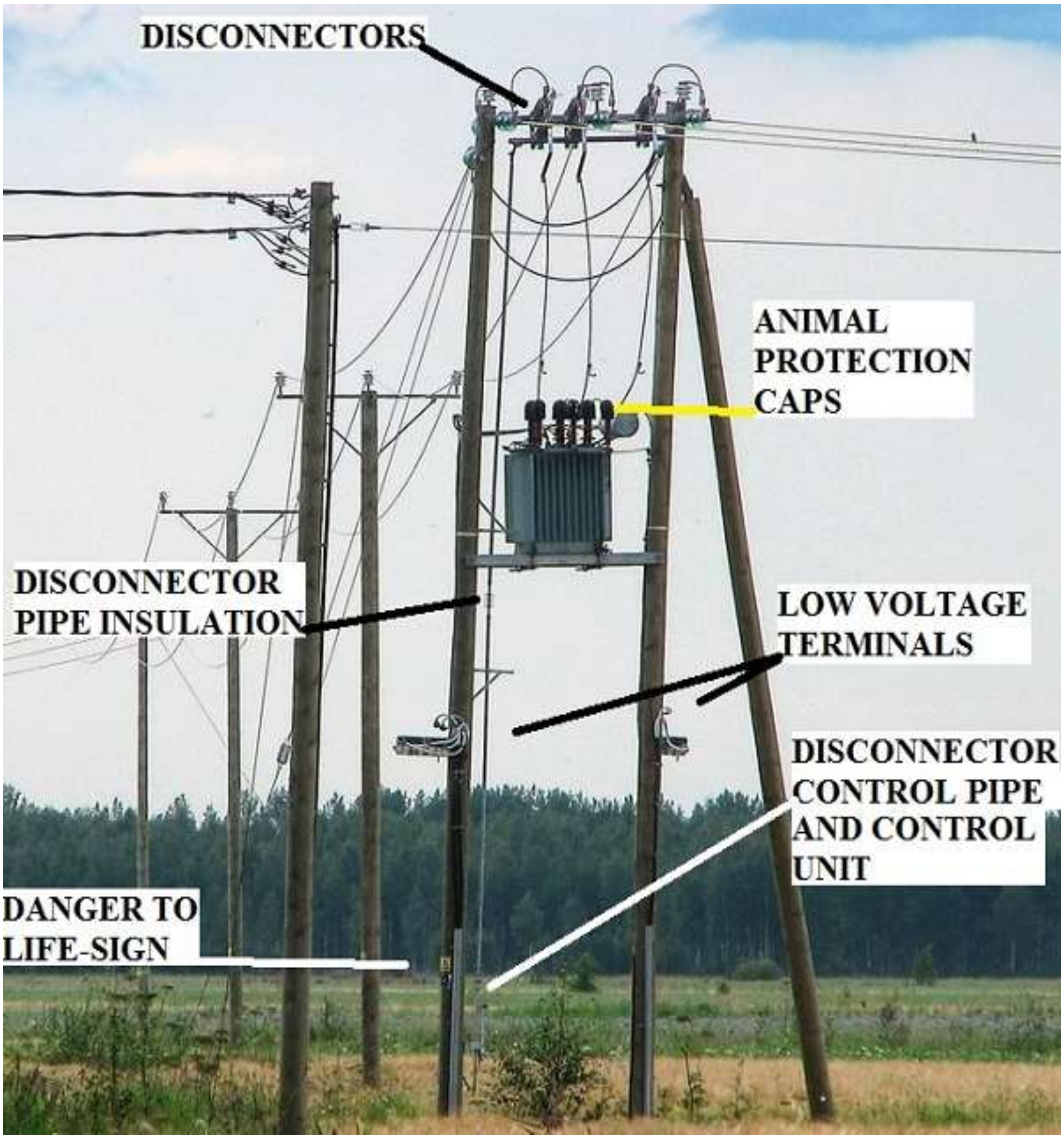
In some areas woodpeckers and black woodpeckers cause damages to the poles. They bore the pole wood in search of insects, but also to stash cones in them. Both of these result in a different shaped cavity. A wire mesh can be wrapped around a pole to restrain woodpeckers from boring more cavities. Fillers are available for the existing cavities but are not used very often, as the holes are patched with metal sheets. In worst cases a metal support is bolted around the pole to prevent it from breaking, but this is used only as a temporary fix as the column needs to be replaced.

3.3.7 Guys

A falsely installed guy wire top end can girdle the pole and break the wood surface. Guy wires, attachments and tighteners are all inspected for rust and defects. Some guys are insulated so the position and condition of the insulating pieces must be inspected. If guy guards are used, the amount must be sufficient to provide sufficient visibility.

3.3.8 Distribution transformer

A pole transformer must be accessible at all times in case it needs to be replaced. The transformer itself is complicated equipment with very minimal clearance so all foreign objects must be noticed and removed. Squirrels and birds occasionally short-circuit a transformer causing an outage, but in rare occasions they also cause permanent damage as the forming arc destroys insulators, rendering the transformer useless. Bird deterrents are used to encourage birds to land elsewhere, but squirrels are so determined that they even find their way into well protected equipment. Transformers are protected from animals by installing composite cups on the bushing insulators and surge arresters to protect the live parts against accidental contact.

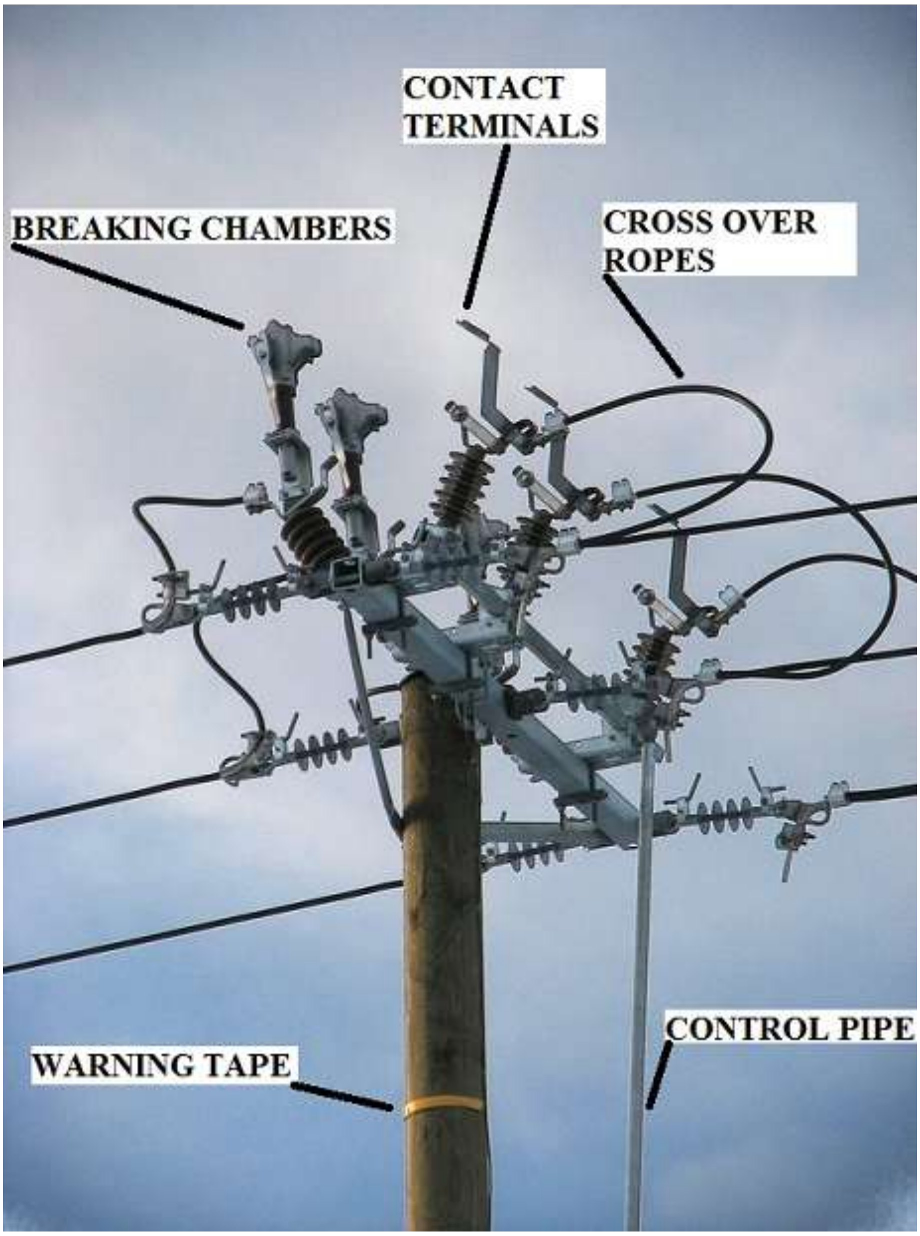


PICTURE 3. 20kV distribution transformer

As the majority of transformers used are oil-cooled, they must be checked for any signs of leaks. This oil is of very low viscosity so all leaks must be reported immediately as the reservoir will keep draining. It is also very flammable so a ruptured case can lead into an explosion in case of a short circuit. The remaining amount of oil should be inspected from the indicator on the side of reservoir. The transformer shell must be rust and dent-free. In a non-hermetic transformer the oil tank cap must be shut tight so that water could not enter the system. The bushing insulators are inspected for cracks and or broken sheds. If installed, the condition of the air drier cartridge is also checked. The rating plate must be visible and intact and the transformer number plate must be visible from the access road for easy identification.

3.3.9 Disconnectors

In addition to the items reviewed in previous sections a disconnector introduces a few new components and like with most equipment, a large variety of configurations are installed out there. What all disconnectors have in common is that they are gang operated so that all three phases are interrupted at the same time, they all have a manual override operable from ground level and that they wear mechanically when operated. The last means that visual inspection alone is not sufficient, so joint rigidness, connection surface wear and general functionality must be tested while the line is dead.



PICTURE 4. 20kV Disconnector

PICTURE 4 shows a modern GEVEA-disconnector with breaking chambers offering greater breaking capacity compared to the traditional breaking whips. Disconnectors are abundant but their task remains the same: to de-energize a circuit providing a visible gap in it. Like transformers, disconnectors also have a number plate which should be visible to the access road, should there be one. Most disconnectors are located in rural areas so signs should face the most probable direction of approach. A danger to life-sign must be attached to the pole or on each column in a double-column disconnector. The control lever must have appropriate identification and it needs to be reliably lockable. /14/

The control pipe, control pipe insulator and disconnector beam must all be properly attached to each other, whereas in a cable operated disconnector the cable tension and condition must be examined. In a more thorough inspection the functioning is also tested, which requires the line to be dead as disconnectors are not designed to handle large currents.

Breaking whips must be set in their respective slots and they are not allowed to be bent as this either lowers the distance between adjacent phases or the arc quenching capability. In a disconnector using arc quenching chambers, the chambers are inspected for dirtiness and leaks. All wire connections must be intact and connections must be solid with no broken threads visible. If the currently inspected disconnector has groundings, their condition is also inspected.

PICTURE 5. Disconnector control device

The control lever must be at highest 1.5 metres from the ground so that enough force can be used to operate it without climbing on the pole. The position of the disconnector must be labeled on the lever with the corresponding 1 / 0.

In a looped medium voltage grid disconnector stations are used to control the electricity distribution in changing operating situations. In rural areas disconnectors are installed in the beginning of a long radial line. Most commonly they are used to re-circuit electricity in order to isolate a faulty part of a grid and to keep the affected area as small as possible. They can also be used to safely keep a grid part dead during maintenance. The increase in the amount of remote controlled disconnectors has made it possible for the grid automation to separate a faulty grid part automatically and extremely fast. A manual disconnector requires a maintenance person to visit the site, which naturally takes more time.

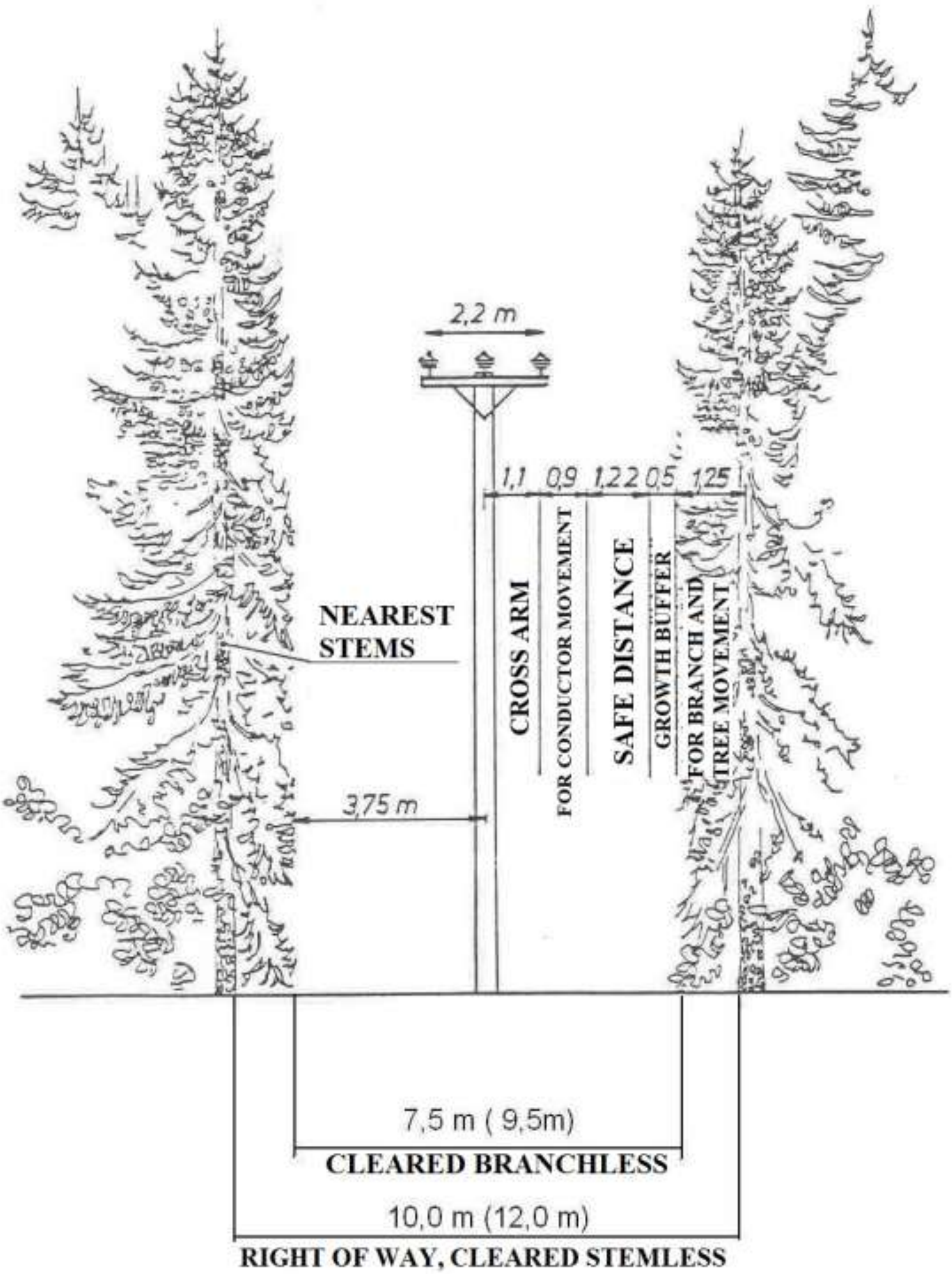
A disconnector station usually consists of several disconnectors in a junction point of the grid. All types of disconnectors have a manual override on ground level with a lockable lever. A lock is used for safety purposes to prevent inadvertent operation. A remote controlled disconnector using an electric motor needs a station service transformer or a pre-existing low-voltage outlet to function and to communicate with the grid control room. Commonly communication happens via radio waves so an antenna must be installed on the unit or, for maintenance reasons, on a separate pole. Some stations also require power to measure different quantities from the grid.

3.4 Vegetation inspection

To be able to offer safe, reliable electrical service, the possessor of the distribution line must maintain the rights-of-way along their power lines. This is done through line area vegetation management. The maintenance requires removing trees, pruning and applying herbicides to slow down and prevent vegetation from growing and interrupting with the lines.

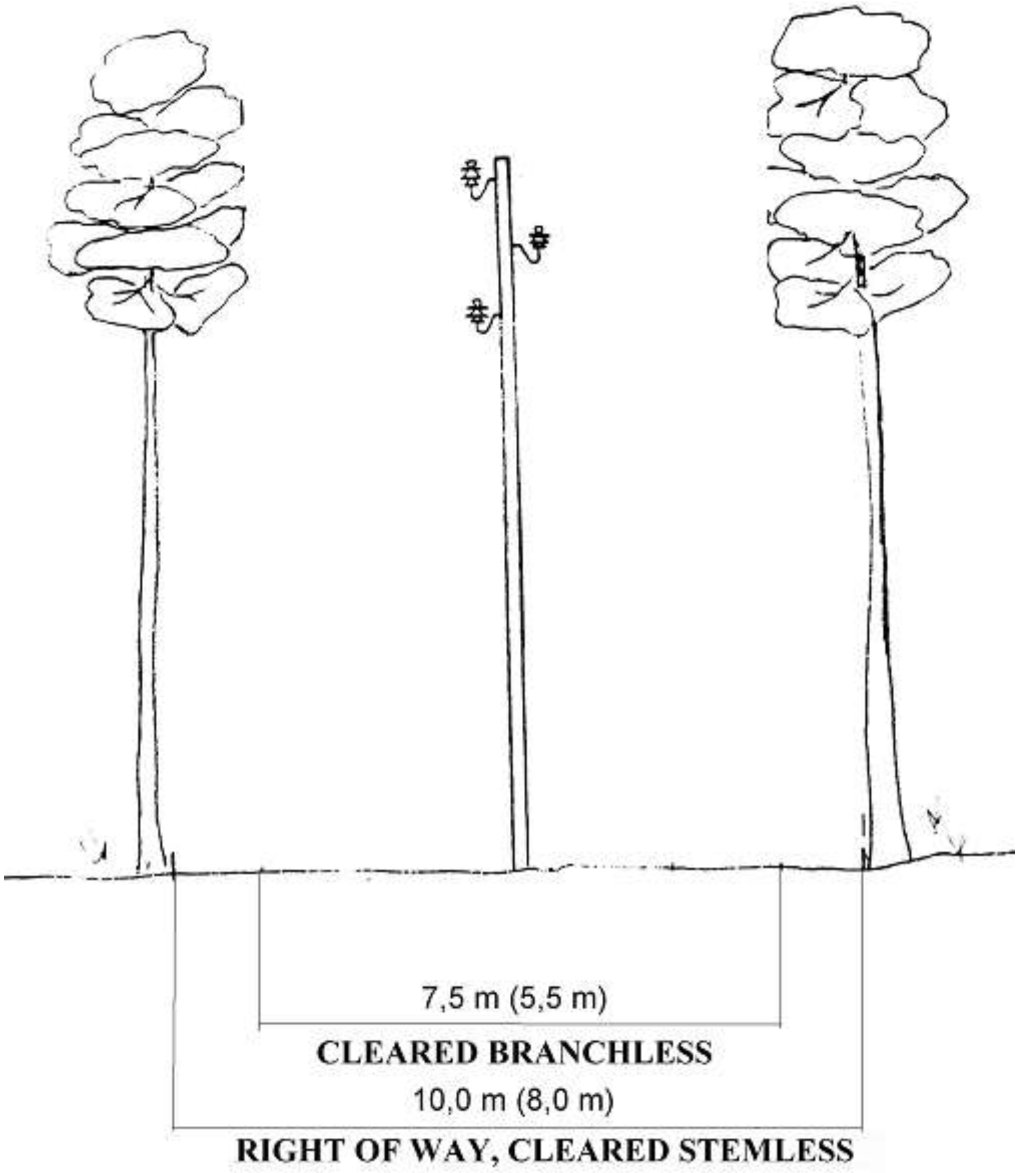
As a term right-of-way refers to the land strip below a power line that must be kept free from all tree stems. Clearance is the narrower land strip, inside the former that must be kept branchless so that no tree branches reach to it. Undergrowth growing in the clearance must be kept relatively short to avoid electrical breakthroughs. The width of each area varies depending on the line, pole and cross arm type as well as the line voltage and span length. A wide cross arm creates a larger conductor offset widening the safety area. Trees, very much like conductors, can sway in changing weather conditions and can bend when snow load increases. A long span means large conductor sag due to temperature changes. Pictures 6 – 9 illustrate the minimum vegetation safety distances in a 20kV distribution line with different conductor types. However, if possible, extending these distances is strongly recommended as a precaution.

Even though air is considered an insulator, in the right conditions an arc can form between an object and an overhead conductor. In order to prevent that from happening the following minimum distances while operating near a 20kV distribution line must be kept: 3 metres from the sides and 2 metres from below. The first number is larger as most working machines and conductors are more prone to sway horizontally, opposed to vertically. Standards do not clearly state the maximum height of the bordering trees, but a guide for bordering forest management in line suggests that mainly coniferous trees should be favoured alongside power lines. These trees are much less prone to bend or break under stress. If the land allows, spruces would be furthermore advantageous as they stunt undergrowth by blocking sunlight effectively. /5/



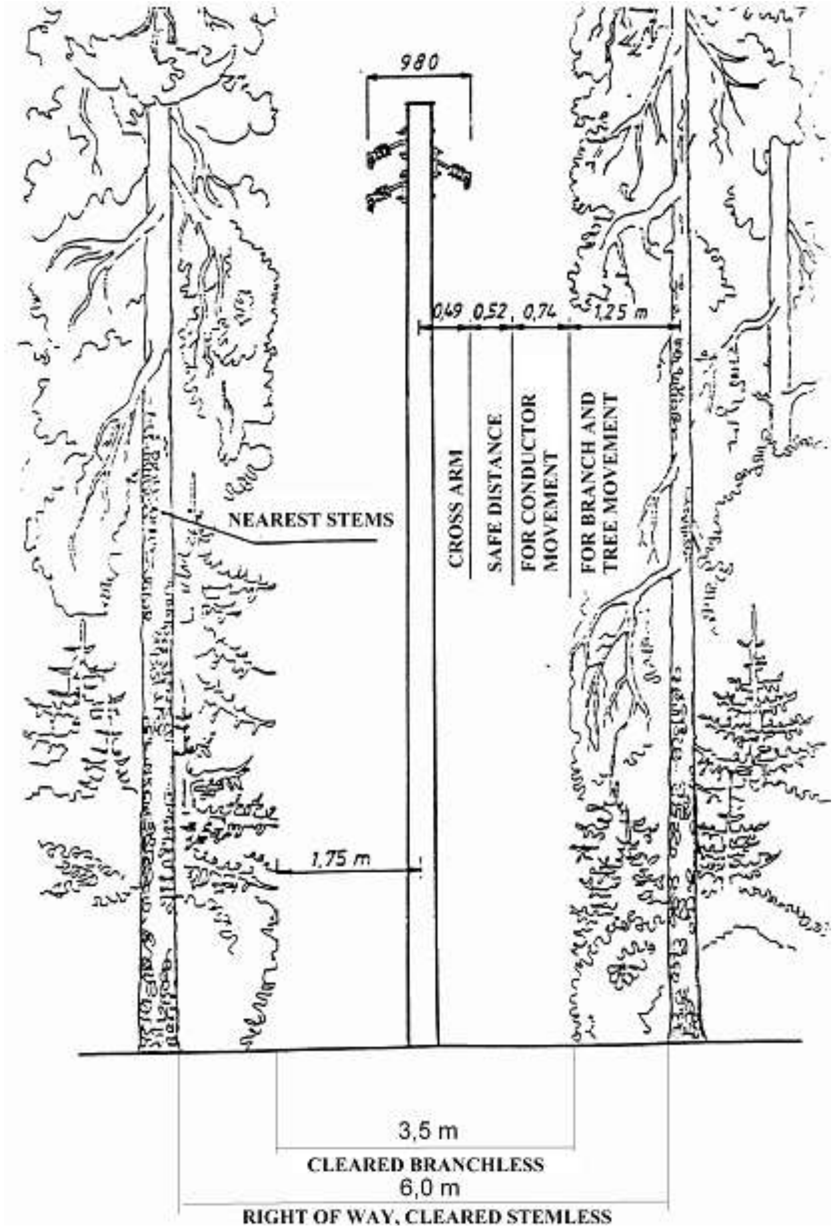
PICTURE 6. 20kV forestland overhead wire line area, horizontal cross arm

An average medium voltage distribution line pole is a self-supporting wooden pole. It has three parallel uncoated metallic phase conductors, which are insulated with ceramic insulators from the metallic cross-arm and placed equidistant. This line type is commonly used as it has been the cheapest to build. The distances are valid for a span length of 80 metres and below. The latter numbers in parentheses are for a span length of 120 metres. /13/



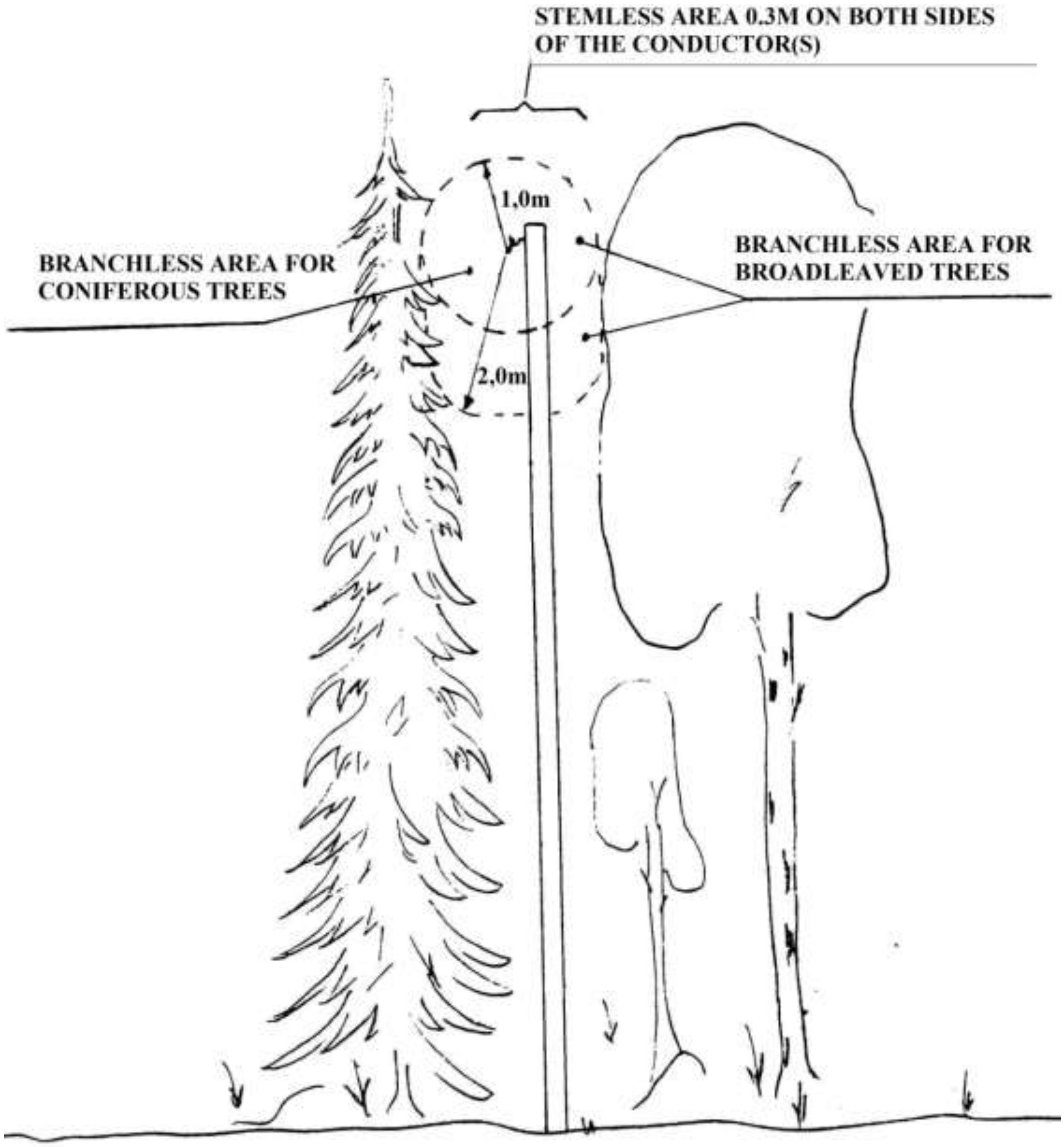
PICTURE 7, 20kV forestland overhead wire line area, individual cross arms

As opposed to the former, Picture 7 shows a pole where the conductors are placed vertically, alternating the side of the pole to allow maximum distance between them. The first measures are for a span length of 100 metres and the latter for 50 metres. This cross arm type is rather uncommon as it has mainly been constructed in the 1950s and 1960s, but some still remain in use. This type of wire placement would require little narrower a clearance as the conductors are not as wide apart, but the trees are still cleared from the same distance in case the wire attachment type needs to be changed. /13/



PICTURE 8, 20kV forestland overhead wire line area, PAS-conductor

A conductor coated with PEX-plastic is called a PAS-conductor. Its coating prevents the disturbances caused by momentary conductor clashing or touching of a foreign object, so the line corridor may be narrowed up to 40%. This not only saves expenses, but allows the usage of overhead conductors in planned areas. /13/



PICTURE 9, 20kV forestland overhead cable line area, SAMKA-conductor

SAMKA is a bundled aerial cable, which is a medium voltage equivalent to the famous low voltage AMKA-cable. As a cable, instead of a wire, it requires very few other components to function well. Polyethylene insulated cables are wrapped around a bare aluminium alloy messenger which acts as the attaching part at a pole, eliminating the need for ceramic insulators. The right of way remains very narrow which allows this cable type to be used in places where a broad right of way in not possible, saving costs in land acquisition. /13/

With higher voltages the distances naturally grow larger. Also the form of the right of way changes to protect the line from falling tall bordering trees. On both sides of the right of way is a border zone with tree height restrictions. All trees taller than the restriction must be topped or logged.

4 Reflection

During the 80's and 90's, the eye-sore distribution lines have been constructed and moved away from roads and out of view. This has kept roadside landscape more aesthetic, but hindered maintenance and fault localization greatly. How could remote sensing data be used to further help power line location planning?

Whereas Arbonaut possesses the requisite knowledge and experience for vegetation inspection and analysis, the company currently does not have qualified personnel to inspect power line components. In order to further develop the automated vegetation clearing analysis the company requires more information and statistics about the speed and cost power line clearing.

Some items of the component inspection are observable automatically from the aerial photographs and some from the LIDAR data. Few examples are pole position, pole height, danger to life-signs, width of clearing and type of cross arm. These could be used to update the grid database, but as some are very easily noticed in manual inspection as well, the cost-effectiveness of automation should be studied. Laser scanning offers accurate dimensions and distances but cannot currently cover an area wide enough for extensive line area vegetation analysis if gathered simultaneously with aerial photographing. The reason for this is that LIDAR should be scanned from an altitude too high to get sharp detailed pictures with the zoom camera. As technology advances, this could change soon.

5 References

Printed references

/5/ Energiateollisuus. Johtoalueiden vierimetsien hoito 2013

/7/ Elovaara, J. & Haarla, L. 2011a. Sähköverkot I – Järjestelmätekniikka ja sähköverkon laskenta, Helsinki: Otatieto

/13/ Verkostosuositus RJ 21-92: Ilmajohtojen Johtoalueet, Sähköenergialiitto ry

/14/ Verkostosuositus YJ8:09 Sähkönjakeluverkon merkinnät, Energiateollisuus ry

Online references

/1/ Fingrid Oy. Pohjoismainen voimajärjestelmä ja liitynnät muihin järjestelmiin.[Referred 4.5.2013]
http://www.fingrid.fi/fi/voimajarjestelma/voimajärjestelmä/

/3/ Finnish legislative database, Amendment to the Highways Act 328/2013, 2013.[Referred 4.5.2013] Available:
http://www.finlex.fi/fi/laki/alkup/2013/20130328

/4/ Finnish legislative database, Government Degree 787/2007, 2007.[Referred 5.4.2013] Available:
http://www.finlex.fi/fi/laki/alkup/2007/20070787

/6/ Finnish legislative database, Government Proposal 20/2013, 2013.[Referred 5.4.2013] Available:
http://www.finlex.fi/fi/esitykset/he/2013/20130020

/8/ Finnish legislative database, Regulation of Electrical Safety 498/1996, 1996. [Referred 4.4.2013] Available:
http://www.finlex.fi/fi/laki/ajantasa/1996/19960498

/9/ Finnish legislative database, Law of Electrical Safety 410/1996, 1996. [Referred 4.4.2013] Available:
http://www.finlex.fi/fi/laki/ajantasa/1996/19960410

/10/ Finnish legislative database, Decision of Ministry of Trade and Industry 516/1996, 1996. [Referred 4.4.2013] Available:
http://www.finlex.fi/fi/laki/alkup/1996/19960516

/11/ Finnish legislative database, Decision of Ministry of Trade and Industry 517/1996, 1996. [Referred 4.4.2013] Available:
http://www.finlex.fi/fi/laki/alkup/1996/19960517

/12/ Finnish legislative database, Council of State regulation 787/2007, 2007. [Referred 10.4.2013] Available:

http://www.finlex.fi/fi/laki/alkup/2007/20070787

Interviews

/15/ Kinnunen J. 2013. Vice President, Head of Utility Services. Arbonaut Ltd. Interviewed January 7th 2013.

/2/ Rajala, J. 2013. Maintenance engineer. Elenia Oy. Interviewed in Tampere January 7th 2013 and via email during spring 2013.

Illustrations

Picture 1. http://calm.iki.fi/tolpat/?p=kuva&id=3823 2010, Photographer Toivo Miettinen

Picture 2. http://calm.iki.fi/tolpat/?p=kuva&id=5544 2011, Photographer Pekka Saarinen

Picture 3. http://calm.iki.fi/tolpat/?p=kuva&id=5432 2011, Photographer Janne Määttä

Picture 4. http://calm.iki.fi/tolpat/?p=kuva&id=4999 2011, Photographer Janne Määttä

Pictures 6 – 9. Verkostosuositus RJ 21-92: Ilmajohtojen Johtoalueet. Sähköenergialiitto ry

Appendices

Removed from the public version