Department of Engineering and Safety

UAV as an inspection tool for power lines in Troms

Assessment of UAVs as a viable alternative to already established methods for inspection of power lines.

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Master's Thesis in Technology and Safety in the High North … 06 2018

Abstract

Power line inspection is one of the most important things in a modern society, and therefore it is important that it be kept in a functional state. Because of this, many methods are used to keep it that way.

There are many factors to consider before using UAVs as a viable alternative to already established methods. Factors such as robustness against harsh weather, limits to its range and battery life are all important factors which will affect the overall usefulness of UAVs compared to other methods.

The main purpose of UAVs in the context of electrical transmission grids is to use for inspection of power lines and poles. Troms Kraft have over 3500 kilometres of power lines above ground, and these must be inspected on a yearly basis according to Norwegian law. Often used methods for this include the usage of helicopters, snowmobiles and by foot, and UAVs could potentially be used as an alternative to these in many situations.

When UAVs are being operated by humans, there are many things that could go wrong, leading to a loss of the UAV. It is important to be aware of these factors, what consequences they could lead to and how to prevent them from happening.

In the county of Troms, harsh weather is nothing new. Harsh weather is often the reason for many problems related to the transmission grid, and the usage of UAVs in such conditions must be assessed to see their viability in such conditions.

Preface and acknowledgements

This master thesis is written as a final assignment in the study program Technology and Safety in the High North, with specialization within risk and reliability, at the University of Tromsø.

Working on this thesis has proved to be quite a challenge, especially since the thesis subject had to change after one month, but in the end, I am satisfied with the final product.

I wish to thank Abbas Barabadi at the University of Tromsø who has helped me with guidance throughout this process. I am especially grateful for him helping me find another subject for my thesis and getting me into contact with people that could help me, when the original subject had to change.

I would also like to thank all the people at Troms Kraft who, on a very short notice, helped me a great deal. This includes Karstein, Sølve, Per-Magne, Britt and Turi who all took their time to help me when I needed it. I would also like to thank them for giving me the opportunity to come with them to Halden for a conference on the usage of UAVs in electrical distribution grids.

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Abbreviations

BLOS	Beyond Line Of Sight
RPAS	Remotely Piloted Aircraft Systems
RO	RPAS-Operator

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1 Introduction

A proper, functional transmission grid is one of the most important things to have in a modern society. Without electrical power, a modern society would simply not be able to function as it should. Because of the importance of keeping transmission of electrical power up and running, a lot of effort must be put into keeping it that way, and power companies spend millions of Norwegian Kroners on this. Therefore, they are always interested in other methods that could potentially save them time and money. Inspection of power lines is something all power companies are obligated to do, and there are several methods for performing these. Helicopters, snowmobiles or even by foot has been used, and are already proven and established methods. In recent years, however, UAVs have seen more and more usage, and as the state of the art has improved, so too has the interest of power companies increased, to be able to use UAVs as a quick and easy method of performing tasks that would normally require lots of resources and effort.

1.1 Description of problem

Through this thesis, I wish to assess the possibilities and challenges related to the usage of UAVs in regards to inspections of power lines, and compare them to other already established methods, mostly inspection with the usage of helicopters.

I also wish to assess the faults that could occur during these kind of inspections with UAVs.

This thesis is partly in cooperation with Troms Kraft, so therefore I will be focusing my attention to the areas that they are responsible for.

1.2 Purpose of Thesis

Troms Kraft have been working with a company called eSmart Systems from Halden, through their Connected Drone project. Connected Drone is a project with the goal of making power line inspections with UAVs a semi-automatic process. They combines the usage of UAVs with image recognition techniques to achieve this, so that the operator would not be required to spot faults or errors, and they must only focus on the navigation of the UAV. Through this project, Troms Kraft has been shown that proper power line inspection is possible with UAVs, and have asked me to explore the possibilities of implementing such an idea in their local area.

2 Research methodology

The methods used in this thesis can mostly be split into two parts, a literature review of the already known theory about the relevant subjects and an assessment of the area Troms Kraft is responsible for in relation to usage of UAV

2.1 Literature review

This first part of the thesis will be a literature review of the already established theory and methods. It will cover the basics of UAVs, everything related to power lines and the different methods that are used for performing inspection on them. This will also talk about their advantages and disadvantages.

There are also many laws related to inspection of power lines and also UAVs. It is important that one is aware of all the laws related to this, so as to avoid trouble in the future.

Finally, the literature review will assess the faults that are common during operation of UAVs. Unfortunately, due to limited knowledge about software and the mechanical details, this thesis will only focus on the causes and consequences of failure in human operation will lead to.

2.2 Inspection of power lines in Troms

This part of the thesis will use weather data to establish many of the operating conditions that one could face when operating UAVs, and will look at the challenges one would have with UAV inspection in these areas. Also, many of the facts stated about Troms Kraft have come through interviews of employees at Troms Kraft.

After the assessment of the weather data, this together with the literature review should give a good indication on whether or not power line inspections using UAV is a viable method in Troms.

3 Literature review

3.1 UAVs (drones)

Unmanned aerial vehicles (UAVs), commonly known as drones, are aircrafts without a human pilot on-board. They can either be remotely controlled by human personnel or they can be programmed to fly a certain route by computers. There are three things which we need for UAV operations to work: a UAV, a controller of some sort (either manually or automatic) and a way to communicate between the UAV and the controller. These three make up what is called an UAS, unmanned aerial system.

UAVs are usually divided into several categories depending on the shape. There are three main categories: a fixed wing drone/UAV, a rotary wing drone/UAV and a multirotor drone/UAV. Fixed wing drones are shaped almost like a small airplane, the multirotor drone often has four or more rotors and the rotary wing drone is a sort of middle ground between the two.

Figure 1: Example of a fixed wing drone
From Farmer's Weekly, Oliver Mark (2014) Retrieved from: http://www.fwi.co.uk/machinery/four-key-questions-about-farm-drones-and-uavs.htm

Figure 2: Example of a rotary wing drone
From Kenyan Aviation (2014) Retrieved from http://www.kenyanaviation.com/wp-content/uploads/2014/04/helicam_chopper_sm.jpg

Figure 3: Example of a multi rotor drone
From Intorobotics (2013). Retrieved from: http://www.intorobotics.com/5-best-examples-of-how-to-build-a-diy-quadcopter/

Fixed wing drones are capable of travelling the furthest and also carry the largest load. The problem with these is that they need to constantly be moving, they cannot stand still. Therefore, they are usually used when larger areas need to be covered. During landing there might also be a need for a larger area with no obstacles, ideally like an airstrip.

Multi rotor drones have the shortest range of the three and can carry the least amount of load. Since they tend to have four or more rotors on them, they are easier to manoeuvre and control in the air. Because of this they are quite good at inspecting smaller areas. Landing and take-off of these types of drones is done vertically, so there are no big requirements like with a fixed wing drone.

The performance of each type of UAV can also be classified by their weight, their range, the height which they can reach and how long they can stay in the air. This is shown in Table 1 below.

Table 1[1]

Category	Weight [kg]	Range [km]	Height [m]	Time in air [hours]
Micro	< 5	< 10	250	1
Mini	< 25/30/150	< 10	150/250/300	< 2
Low range	25-150	10-30	3000	2-4
Medium range	50-250	30-70	3000	3-6
Great height/long time in air	> 250	> 70	> 3000	> 6

The usage of UAVs have some advantages which can make them more suitable for certain tasks. One of these advantages is the fact that they are quite lightweight, and have a quick response time should they be needed. In theory, you would only need a mode of transportation for the UAV and qualified personnel to operate it. For smaller UAVs, its size can also be quite advantageous, as this can allow for closer inspection of areas of interest. Combine this with high quality cameras or sensors, and it can make inspections much easier and give results which could not be achieved from a further distance away.

[1] A. M. Samad, N. Kamarulzaman, M. A. Hamdani, T. A. Mastor og K. A. Hashim, The Potential of Unmanned Aerial Vehicle (UAV) for Civilian and Mapping Application (2013)

Since the UAVs are unmanned, a lot of risk factors related to humans are removed. This is especially good for areas where an event such as a natural disaster has happened, and the area is not deemed safe for humans to be in. A UAV could then be used as a tool to survey the area and get a better grip on the situation and area, without actually risking any human injuries.

UAVs also have an advantage in that they can carry different types of equipment depending on the task they are set to be doing. There are also different methods for remote control of the UAV. For remote controlling it is possible to use satellite systems like GPS or similar. These kind of methods will require the UAV to be equipped with a satellite signal receiver. Once the receiver has been installed, we can then use known coordinates from satellite systems and send them to the UAV which will direct itself based on that information.

Although there are advantages to using UAVs, there are also some disadvantages. Firstly, they are quite expensive. Depending on the overall quality of the UAV, with regards to factors such as robustness, range and the amount of time it can spend in the air, the cost can be very high. Given that they are so expensive to begin with, it becomes even more important to treat the UAV as good as possible. If during a task the UAV is not recoverable or can not be repaired, then that means another has to be bought, which leads to even more expenses. Because of this, the one who is piloting the UAV will be required to have a lot of prior knowledge and experience to be able to bring the UAV back in a functioning state.

To be able to make the best use of a UAV, the operator should be able to operate the it close to the maximum range that it can handle. If the operator is using a UAV with a very long range, then this could mean that the operator will lose sight of it. This is known as flying «Beyond Line Of Sight», and requires even more experience from the operator and increases the possibility of losing or destroying the UAV. On top of the added requirements from the operator, Norwegian law states that if you want to operate BLOS, then one has to fulfil several requirements with the Norwegian Civil Aviation Authority[2], which may or may not slow down the operation if there is a lot of aerial traffic in the surrounding area.

[2] https://lovdata.no/dokument/SF/forskrift/2015-11-30-1404

Another disadvantage with UAVs, especially the smaller models, is the fact that they will have trouble operating in harsh weather. Because of their size, high wind speeds will affect the stability of the UAV, leading to it becoming significantly more difficult to operate at a desired level, and can in a worst case scenario lead to the operator losing control of the UAV.

3.2 Power lines

The main purpose of electrical power lines in a transmission network, is to supply electrical power to wherever or whoever might need it. Therefore, robust and safe power lines are of upmost importance to ensure that these are operational at all times. Should a power outage occur then it can lead to huge consequences, as was seen in the Northern parts of Norway in 2015.[3]

To transfer all this electrical power to wherever it might be needed, huge pylons have been built which supports these high voltage power lines, and carries them to the desired location. Power lines are categorised into high-voltage and low-voltage, where high voltage is defined as being higher than 1000 volt and everything below that is defined as low voltage.

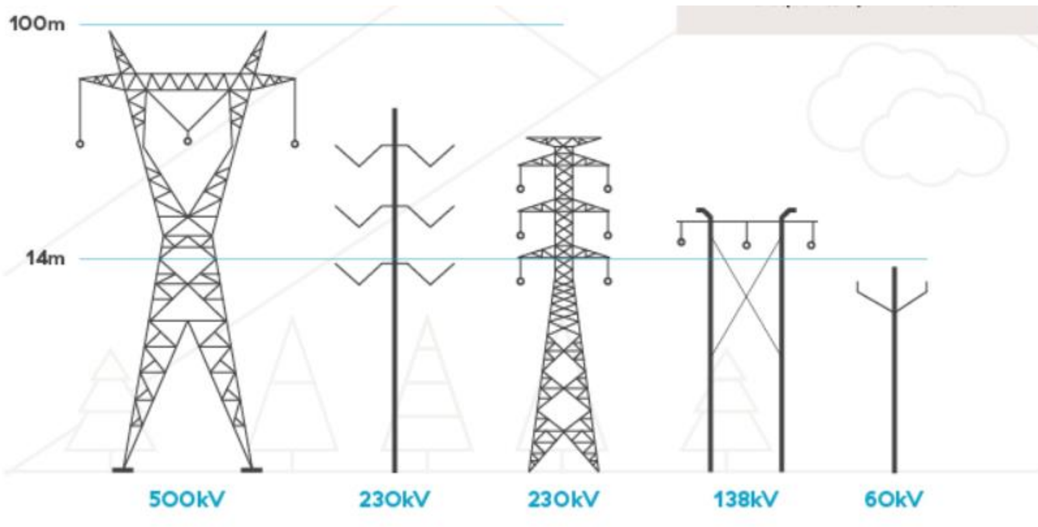

Figure 4: Different types of transmission lines
BC Hydro. Retrieved from: https://www.bchydro.com/safety-outages/trees-power-lines/know-power-lines-infographic.html

[3] https://www.nordlys.no/strombrudd-morkla-store-deler-av-nord-norge/s/5-34-78369

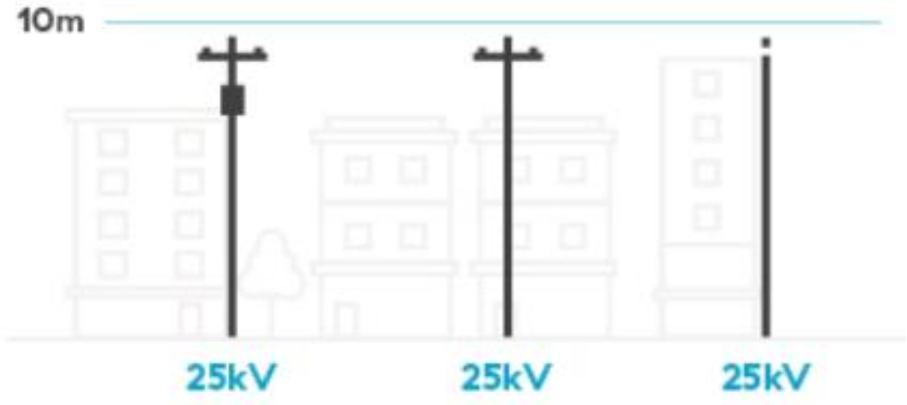

Figure 5: Different types of distribution lines

BC Hydro. Retrieved from: https://www.bchydro.com/safety-outages/trees-power-lines/know-power-lines-infographic.html

To ensure the proper distribution of electrical power, the total transmission network is divided into three: the main grid, the regional grid and the distribution grid. The main difference between these three are the voltage with which power line must be able to handle.

The main grid is mainly owned and operated by the Norwegian government through their company Statnett. Its main purpose is to ensure a proper supply of electrical power and mode of transportation to the designated regional power companies. They operate with high voltages usually transmitted through overhead lines. In Norway, these lines operate at 132, 300 and 420 kV.

The reasoning for the high voltage in the power lines is because this leads to less energy loss. Instead of using overhead lines, it could also be possible to transmit the power underground should one desire that. This leads to a more aesthetically pleasing solution and are less affected by bad weather, but will also increase the installation costs. On top of this, should an incident occur where the underground power line would need repair, then the maintenance costs will also increase.

The regional grid is, as implied by the name, the grid that cover larger regions and counties. It's operating voltage is lower than the main grid, but higher than the distribution grid. In Norway we usually see voltage levels of 66 or 132 kV. The main purpose of the regional grid is to receive and transform the high voltage electrical power from the main grid, into a lower voltage and distribute it further towards the distribution grid.

The last grid, the distribution grid, operate with the lowest voltage out of the three. These voltages are usually 230 V for distribution to private homes and 420 V for businesses and industry. Before the electrical power is actually transmitted to homes and businesses, it is in fact transmitted as high voltage which has been transformed at a station connected to the regional grid. This high voltage is usually either 11 kV or 22 kV as it is transmitted towards the customers, before another smaller transformer actually turns the high voltage power into a lower voltage.

To be able to change these voltages, power companies use stations for transforming the higher voltages, like from the main grid to the regional grid, and smaller transformers when the voltage is lower, like on the distribution grid before it is transmitted to customers.

Figure 6: Power lines with a small transformer.
Mjøsmuseet, Sigurd Bernhard Røisli (2017) Retrieved from: *https://digitaltmuseum.no/021017325542/lysstolper-linje-med-transformator*

Figure 7: Station for transformation
Store norske leksikon, Knut Rosvold (2014) Retrieved from: *https://snl.no/transformatorstasjon*

3.3 Inspection of power lines

The first thing one needs to know about inspection of power lines, is why is must be done. Power lines are extremely important in an electrical transmission grid, and is used all the way from power plants to the consumers. It is therefore of upmost importance that these are kept at a high standard, and to keep the number of faults as low as possible. Inspections are therefore done often and routinely, with several tools to help this process be performed as good as possible.

There are several types of inspection that can be performed, each serving their own purpose to make sure a proper transmission grid is maintained. The inspections that are mostly used is power line inspection, top inspection and thermographic inspection.

Power line inspection is a very basic form of inspection compared to the other two. This involves an inspection, by foot, air or any other means necessary, of the power mast with its corresponding power lines. Here the inspectors are looking for glaring faults that may or may not require immediate actions.

Top inspection is a more detailed form of inspection, where the inspectors are looking at the components at the top of a power mast. This form of inspection can also be performed on foot, given that proper equipment is being used and the conditions allow for climbing of the mast, but is often performed using helicopters or other means of achieving images from an aerial perspective.

Thermographic inspection is different from the others in that it requires equipment to detect heat values in the power lines to see if there is any chance of overheating in the power line and in the joints connecting them. This type of inspection can be performed on foot or by air. Inspections by air will require better thermographic cameras, as it will usually be harder to come as close as you would on foot.

When performing inspections on power lines and poles, one has to look out for several different types of errors which may occur. Some faults can be related to the vicinity of forests and trees, where the trees grow too close to the lines. This is dangerous because they can potentially create a path for the electricity to travel to the ground. If such a path is created, then there is a huge risk for both humans and animals in the surrounding area to come in contact with this and be electrocuted, which in a worst case scenario could lead to fatal injuries. they are at a huge risk of being electrocuted and in the worst case, be fatally injured. This will affect both humans and animals in the surrounding area. Also, during very long dry spells of weather, the risk of fire will also be a possibility.
Another fault that may occur in the vicinity of trees is when they are lying across the power line. This could happen due to extremely strong winds or even lightning strikes for instance.

If a tree is lying over a power line, then it must be removed as soon as possible. Larger trees can in a worst case scenario make the load too much to bear for the poles or pylons, and can cause extreme damages to them.

One phenomenon, which could be a serious issue in Norway, is that of icing on the power lines. In climates with high precipitation in the form of snow, and low temperatures for large portions of the year, icing can be a huge problem. Because of the large amounts of ice that can accumulate on the lines, a lot of extra weight is out on them. Combined with strong winds, the lines can whip violently, which can cause them to break from the pylon or wooden pole.

Another process that can happen is called an icing flashover. This happens when ice formations appear on the insulators which decrease their electrical strength, and can lead to flashover on the surface of the line at the actual operating voltage. To prevent this from happening, power companies use several methods for de-icing the power lines. One of these methods is by using a controlled short-circuit to heat up the power line in question.[4]

Figure 8: Example of tree lying across power lines.
BC Hydro. Retrieved from: https://www.bchydro.com/safety-outages/trees-power-lines/pruning-removing-trees/removing-hazardous-trees.html

[4] https://www.hydro.mb.ca/outages/ice_on_power_lines.shtml

Figure 9: Extreme case of icing on power lines
Vindteknikk, Ole Gustav Berg. Retrieved from: http://www.vindteknikk.com/news/new-knowledge-about-icing-on-power-lines

Other common faults that can occur independent of the climate and time of year are cracks in the poles, woodpecker holes and missing toppads. Many of the poles used for transmitting lower voltages are made out of wood, and in a climate that can have both very cold winters and moderately warm summers, then cracks in the wood are bound to happen. Combine this with strong winds and heavier loads from potential icing on the power lines, and it is easy to understand why such damages can occur. When this is spotted, it is up to qualified personnel to determine whether or not the damages are too big to ignore, and the pole must be replaced.

Holes made by woodpeckers in power lines can also become a problem. Woodpeckers will use the wooden poles as nests, pecking away and causing damage to the pole. If nothing is done for a long time, then the pole will be so heavily carved that one must actually replace the entire pole.

Figure 10: Wooden pole with several holes from woodpeckers.
Gizmodo, Gary Cutlack (2017) Retrieved from: http://www.gizmodo.co.uk/2017/08/stupid-woodpeckers-are-destroying-electricity-poles/

Top pads are usually used in Norway to protect electric poles from the rain. Because of the colder winters in many places, this is even more important because when the water freezes and expands, it will cause even more damage to the wooden poles. Especially on wooden poles that already have smaller cracks in them where the water can enter.

Figure 11: Example of wooden pole missing top pad.
Van Nhan Nguyen, Robert Jenssen, Davide Roverso, (2018). Retrieved from "Automatic autonomous vision-based power line inspection: A review of current status and the potential role of deep learning"
https://www.sciencedirect.com/science/article/pii/S0142061517324444

3.4 Inspection using UAV

When performing an inspection using UAV, we can divide the process into several smaller steps all the way from the actual transportation of the UAV to the site, all the way to the actual task has been performed.

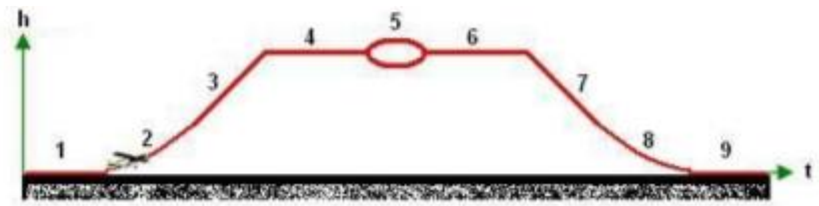

Figure 12: Phases of drone flight

Beatriz Juliana Martins Franco, Luiz Carlos Góes. (2007) Retrieved from: "Failure Analysis Methods in Unmanned Aerial Vehicle (UAV) Applications" Retrieved from:

http://abcm.org.br/app/webroot/anais/cobem/2007/pdf/COBEM2007-0221.pdf

From Figure 8, taken from Beatriz Franco (2007)[5], we see that the process is divided into nine smaller tasks. These are:

1. Establishing base, start-up of drone.
2. Take-off.
3. Ascent.
4. Cruising to desired location.
5. Performing of desired action.
6. Crusing towards base.
7. Descent.
8. Landing.
9. Making drone ready for eventual further transportation.

[5] http://abcm.org.br/app/webroot/anais/cobem/2007/pdf/COBEM2007-0221.pdf

During inspection, the most used equipment used on a UAV is a regular camera, capable of capturing images of a high quality. The quality of the image is important so as to not have any doubt over possible deviations or errors spotted at the power line or pylon.

It is also possible to equip the UAV with thermal sensors which can be useful for detecting overheating in the power lines. Overheating is not desired as this will lead to expanding of the power lines, which in turn could lead to the lines becoming longer, increasing the slack and makes it so that the lines sag more than desired.

Perhaps the most important attribute of using UAVs for inspection, is the ability to quickly store images in a database. With an optimal system, it should be able to take many pictures and, within a short timespan, be able to upload or send those pictures to a larger database where the images are saved for further inspection. These databases should be intuitively easy to navigate, as this will save time for the human operator who wants to use or check these images.

Once the images are stored in the database, there are two possible ways of determining whether or not further actions are required on the inspected power line or pylon. One possibility is a fully manual inspection of the image by a qualified human operator and the other is an automatic method where a computer uses advanced pattern recognition techniques to automatically distinguish potential errors from other images which show no errors. More advanced systems will also be able to grade the severity of the error. The images showing errors are then shown to a human operator who must then decide what further actions are required for the given situation. If a grade of severity is also shown, then this will make it easier for the human operator to decide where to start.

3.4.1 Manual operation

The most normal mode of operating a UAV is with a human controlling it from a given base of operation. This requires the operator to have sufficient tutoring and experience with regards to the surrounding conditions and knowledge of potential for bad weather. The UAV can be operated so that one always has visual sight of it whilst it is hovering, but there could also be a need for flying it outside of line of sight, which will require even more experience from the operator. This requires a camera on the UAV which sends a live feed to the base of operation, which the operator then must use to manoeuvre it.

A disadvantage with this method is that all the work is put on the human operator, and the factor of human error must be taken into consideration.

Figure 13: Example of what a drone control screen used by an operator could look like. Wikimedia, Tom Sulcer (2015) Retrieved from: https://commons.wikimedia.org/wiki/File:California_photo_of_control_screen_of_a_drone_aircraft.JPG

3.4.2 Automatic operation

In an attempt to eliminate the human factor when operating UAVs, a lot of research has been put into being able to perform these kinds of inspections with an automated UAV, without needing any additional input from a human operator. The advantage this has over normal manual operation is that you eliminate the human error in manoeuvring the UAV. On top of being able to fly the given route without any human intervention, some are also able to automatically identify power lines and components on the pylons.

Unfortunately, the state of the art at the moment is not where it needs to be. Because of all the factors, especially related to harsh weather and difficult topography, fully automatic UAVs have not seen much usage as of yet. On top of this, because power lines are quite small, they are hard to represent in an image recognition algorithm, which makes tracking and detecting these lines very difficult, which again will make it harder for the UAV to navigate in a proper fashion. Despite all these challenges, more and more research is being put into trying to make UAVs operate as autonomously as possible, so it is possible that this method will see more usage in the future.

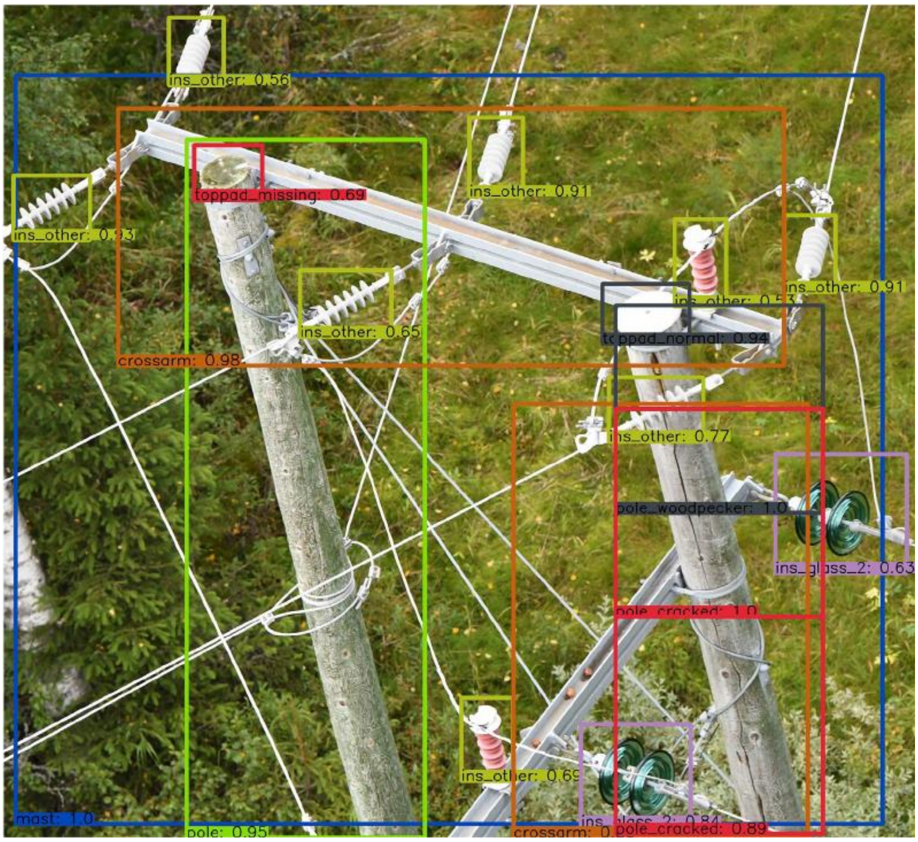

Figure 14: Example of power line inspection where faults are automatically detected.
Van Nhan Nguyen, Robert Jenssen, Davide Roverso, (2018). Retrieved from "Automatic autonomous vision-based power line inspection: A review of current status and the potential role of deep learning":
https://www.sciencedirect.com/science/article/pii/S0142061517324444

3.5 Inspection using helicopter

When performing an inspection with the use of helicopters, several personnel are required. First and foremost, one would require a pilot to steer the helicopter. This pilot should have much experience with flying a helicopter in different forms of terrain as the power lines could be located on mountains, in forests or over large bodies of water. On top of this, they should be able to handle harsh weather, such as strong winds, since this often lead to faults with power lines.

In addition to the pilot, an inspector and camera operator must be present. It is possible for the inspector to also operate the camera, but is much easier with two separate people. The main objective of the person operating the camera is to capture good quality images of everything that could be of interest. This includes components, such as transformers and toppads, the pylon itself and also the area around the pylon and under the power line. When the inspection is complete, and the helicopter has landed, a team of qualified personnel go through the video and images in detail to try and identify faults that are hard to spot when flying over with a helicopter.

The main objective of the inspector on board the helicopter is to identify obvious faults related to the pylons or power lines. This could mean something like trees too close to the power line or even lying on top of them. When the inspection route is completed, the inspector also helps with the images and video to identify smaller mistakes.

Figure 15: Power line inspection using helicopter

Helikoptertjänst. Retrieved from: http://www.shtab.se/english-information-3517877

The main advantage for performing such inspections is that they are performed in a very quick manner. Helicopters are able to cover long distances and can fly at a relatively high speed should it be necessary. On top of this, should they need to stop or circle around a pole or pylon to take more detailed images and videos, then that is also a possibility.

One of the main disadvantages though with using helicopters is the high cost that comes with it. Often power companies must hire a helicopter and a corresponding pilot to be able to perform the task, and it is rarely cheap. The human factor must also be taken into consideration, as both the inspector and the person operating the camera can overlook important details. Additionally, the risk of human lifes is also a factor which must be taken into consideration. This could happen if the helicopter gets in contact with a live line or if the pilot loses control, and end up crashing.
Finally, there is also an environmental factor to be considered. Helicopters make a lot of noise which could disturb the local area if an inspection takes longer than it should. They also consume fuel, which again can affect the surrounding area.

3.6 Inspection by foot

This is the most basic form of inspection one can perform when compared to the other inspection methods. Usually this is performed with two inspectors to try and make up for the human error that could occur. With only one inspector, the chances of missing an important detail increases. These kinds of inspections are most used in areas where there wouldn’t be any purpose to performing them with a helicopter or other means. This could be in heavily populated areas where the lines are easy accessible, but could also be places with challenging surroundings, where large helicopters would have trouble reaching.

One of the main advantages with inspections by foot, is the quick response time. If urgent inspections are needed in the vicinity of human settlements, and a response team is nearby, then the inspection will be carried out much faster than other methods. It is also the cheapest alternative for inspection.

The main disadvantage comes into play when inspections are needed in harsh terrain, where there is next to no way of approaching the actual inspection area by foot. In such a case, aerial inspection would be the only alternative.

Additionally, when performing inspections from the ground, the inspector may not get as good of an overall view of the surrounding area as one would if they were sat in a helicopter above ground.

3.7 Norwegian laws related to power line inspection and use of UAV

Because of the importance of keeping a reliable infrastructure for distribution of electrical power, many laws and regulations have been put in place to make sure this happens. One of these regulations are specified in «Regulations about electrical supply constructions» § 6-8, from 2005[6], which states that all power lines above ground must be inspected as deemed necessary to control that they are in a regulatory condition. Additionally, the Norwegian Directorate of Civil Protection and Readiness say that power lines must be inspected at least once a year, and when they are exposed to abnormal strains.[7] Abnormal strains could be due to strong winds and when there's a high chance for icing for instance.

Another regulation that power companies must fulfil, is the inspection of the top of the power mast, named top inspection. These must be done every 10 years for every power mast in the grid, or after events that could lead to abnormal strain on the grid.[8]

There are many regulations regarding the usage of UAVs[9], and one thing one must be aware of is the fact that UAVs has to give way for other manned aircrafts. Another thing to be aware of are all the requirements needed to be allowed to fly different models of UAVs. These are categorised as RO 1, 2 and 3. All the requirements for each category are specified from § 22 to § 46[10], and if one is qualified to operate under a higher quality, then they are also allowed

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6 https://lovdata.no/dokument/SF/forskrift/2005-12-20-1626
7 https://www.dsb.no/lover/elektriske-anlegg-og-elektrisk-utstyr/veiledning-til-forskrift/veiledning-til-forskrift-om-elektriske-forsyningsanlegg/#lavspenningsluftlinjer
8 https://www.dsb.no/globalassets/dokumenter/elsikkerhet-els/elsikkerhet-magasinet/2004-12-elsikkerhet-66.pdf
9 https://lovdata.no/dokument/SF/forskrift/2015-11-30-1404
10 https://lovdata.no/dokument/SF/forskrift/2015-11-30-1404

to fly smaller category UAVs. It is important to note that operators that fall under the category RO 1 are only allowed to operate during daylight, and that operators in the other two categories will also require a risk analysis about the operations.

Before one is allowed to operate a UAV in the two highest categories, RO 2 and 3, a course with a corresponding exam must be taken and passed. This is an extensive course taught by the Norwegian Civil Aviation Authority, and takes the applicants through several smaller courses which span actual operation, including BLOS, to all the laws related to operation of UAVs.

UAVs are mentioned in relation to the Norwegian Law of Aviation under § 15-1[11]. This paragraph states that exceptions from this can be made for aerial vehicles without a pilot on board, but that these exceptions would have to be decided by the Ministry of Transport and Communications.

[11] https://lovdata.no/dokument/NL/lov/1993-06-11-101

4 Fault analysis for UAV

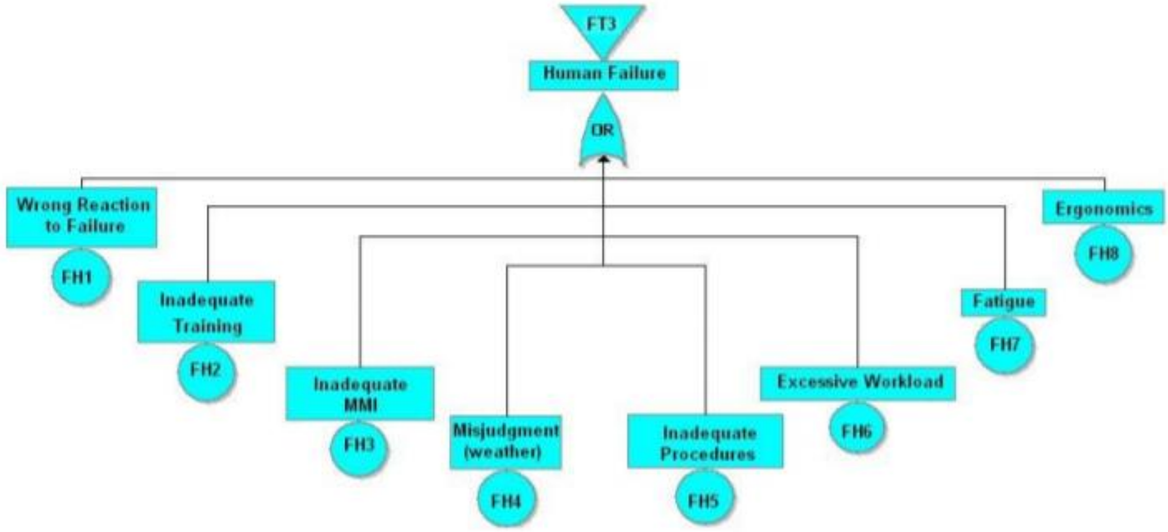

Figure 16: Fault tree for human failure in operation of UAV

Beatriz Juliana Martins Franco, Luiz Carlos Góes. (2007) Retrieved from: "Failure Analysis Methods in Unmanned Aerial Vehicle (UAV) Applications" Retrieved from: http://abcm.org.br/app/webroot/anais/cobem/2007/pdf/COBEM2007-0221.pdf:

As can be seen in the fault tree above from (Beatriz Franco, 2007) we see that there are several factors which can lead to loss of UAV, and make them no longer usable. Because of all these factors, proper procedures and tutoring for all possible outcomes is required to make full usage of UAVs.

4.1 Wrong reaction to failure

There are different ways for a UAV to fail. This could be either due to damages to the UAV which makes them unfit to fly or loss of contact with the control system on the UAV. If this happens, then it is important that the operator knows fully what should be done, and the consequences such a failure should happen. If operating in an area with difficult topography, failure could lead to the UAV becoming non-recoverable, and would have to be replaced. To mitigate the chances of this happening, the operator should be aware of the surroundings, and keep an eye on the state of the UAV. If the UAV is noticeably more unstable than what it should be or not responding very well to manual inputs from the operator, then this could mean that failure is imminent. The operator should then try to pilot the UAV so that it is recoverable so as further expenses are reduced.

4.2 Inadequate training

Unfortunately, there are no requirements from the Norwegian Civil Aviation Authority for prior flying experience from applicants who want to take the exam for flying in the two higher categories, RO 2 and 3. This means that it can be difficult for the authorities to assure the quality of their flying prior to being eligible to operate in the higher categories. It is therefore important that operators acquire that experience before performing different operations with UAVs, so that unwanted events is kept to a minimum.

4.3 Inadequate Man Machine Interface

When operating a UAV, it is important that the control screen, which the human will use to navigate the UAV, is made in such a way that an operator will not have much issues with reading or processing the information that is being given to them. An operator should be able to easily read vital information from the screen such as time in air and the total height that has been traversed. The screen should also provide a camera live feed of proper quality so that the operator easily can figure out where the UAV is stationed compared to its surroundings. This is especially important when flying BLOS, as there would be no other way for the operator to actually see how the UAV would fare against its surroundings.

4.4 Misjudgement of weather

Especially in areas with a history of harsh weather, it is important that operators are aware of the conditions they will be working in. Strong winds and heavy precipitation will affect the stability and operation of the UAV, making tasks more difficult to execute. Heavy snowfall can also impede the vision of the operator, which makes it easier to lose sight of the UAV and potentially crashing and destroying it, leaving no other option but to replace it. It would be a good idea to check historical weather data, as well as the local weather forecast, before setting out to perform actions.

4.5 Inadequate procedures

As can be seen in Figure 12, there are many steps to a proper take-off, flight and landing of a UAV. Because of this, it is important that guidelines for each step is specified, and that the operator is aware of these, knows them and how to perform each step. Failing to do so could lead to loss of the UAV.

4.6 Excessive workload and fatigue

With many inspections to perform, and a long grid to perform it on, human fatigue is bound to set in at some time because of the excessive workload that is required. Because of the long grid, inspections could take an entire workday, and fatigue leads low morale and more errors being made by the operator, which again could lead to loss of the UAV.

4.7 Ergonomics

When performing inspections with a UAV, the operator will have some sort of control screen in front of him with levers or other mechanisms to control the UAV. It is important that these control mechanisms be made in such a way that is ergonomically good for the operator. Failure in having ergonomically sound mechanisms can lead to fatigue in a shorter amount of time that it would normally. In a worst-case scenario, very long usage, over long periods, of such mechanisms could even lead to hand injuries to the operator.

5 Inspection of power lines in Troms

Troms Kraft is the main distributor of electrical power in the county of Troms. They have approximately 3500 kilometres of power lines above ground under their command and it is up to them to keep these in a proper state and up and running.

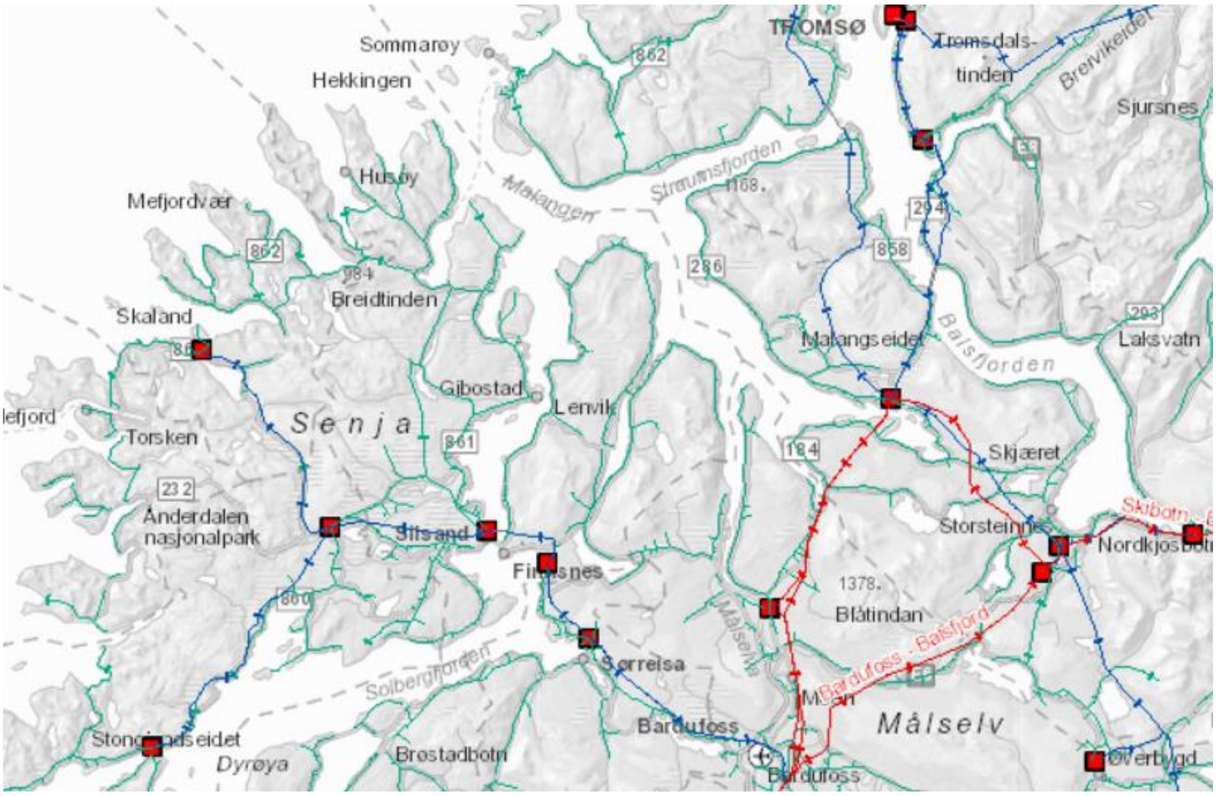

Figure 17: Parts of the transmission grid south of Tromsø

NVE ledningsatlas (2014). Retrieved from: https://gis3.nve.no/link/?link=nettanlegg

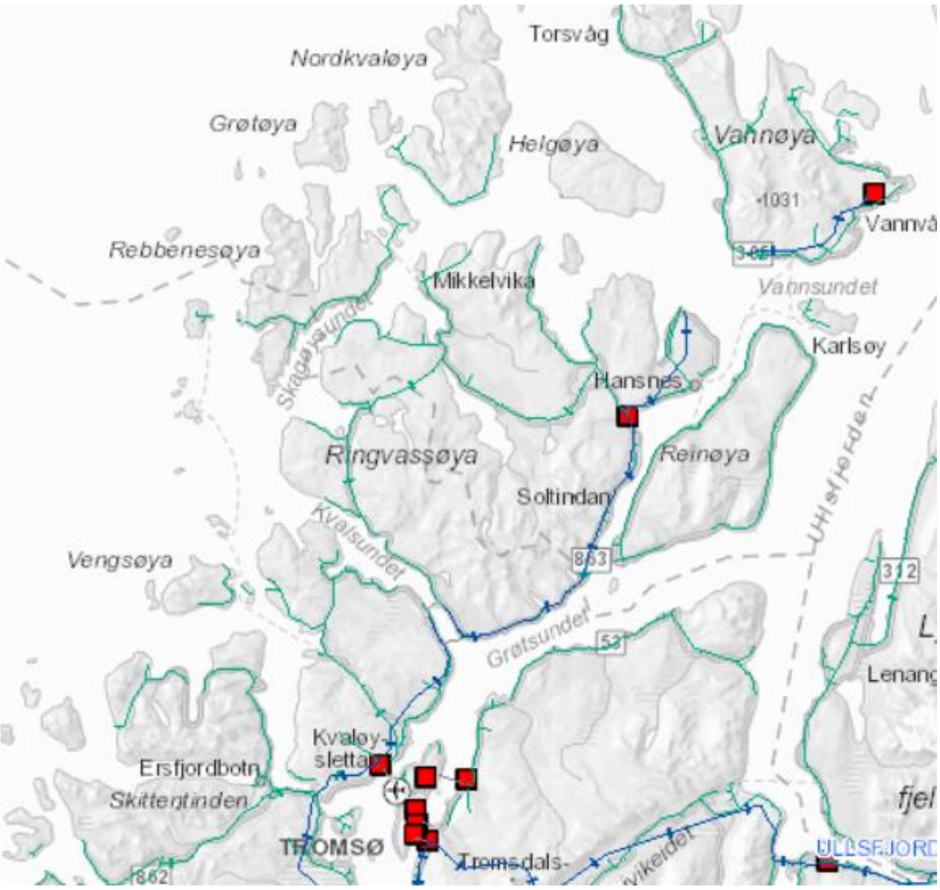

Figure 18: Parts of transmission grid north of Tromsø.
NVE ledningsatlas (2014). Retrieved from: https://gis3.nve.no/link/?link=nettanlegg

As can be seen on the maps in Figure 17 and 18, the power lines cover very large areas. The red lines in Figure 17 indicate high voltage power lines from the central grid, the blue lines represent power lines of the regional grid, while the green lines represent the power lines on the distribution grid. The red boxes are stations for transforming.

Because of Norwegian law, Troms Kraft is obligated to perform inspections on the power lines. One of the requirements is that top inspection must be performed every ten years. Because of the length of the total grid, this is done by performing top inspection of 10 % of the grid every year, so that after ten years, they will have fulfilled the requirement from the Norwegian government. This is usually done with the usage of helicopters, as this allows for overhead images onto the mast. When Troms Kraft performs top inspection, they will capture a minimum of three images of the top of the mast to make sure that no details are missed, and will take more images should it be required.

They are also obligated by Norwegian law to perform power line inspections at least once a year. This is especially important after periods of harsh weather, where the transmission grid will have been put under a lot of abnormal stress. Like when performing top inspection, this can be performed using helicopters, but also on foot or by snowmobile. The main difference being that for top inspection, one must take in to account the longer time one will spend inspecting each power line.

One of the main reasons for using helicopters for these kind of tasks, is the fact that they can cover large areas in a short amount of time. Given the vast scope of power lines that must be inspected, usage of helicopters has become more or less the go to way for Troms Kraft to perform these kind of tasks. They are especially useful when inspection is needed in more remote locations who are more exposed to harsh weather.

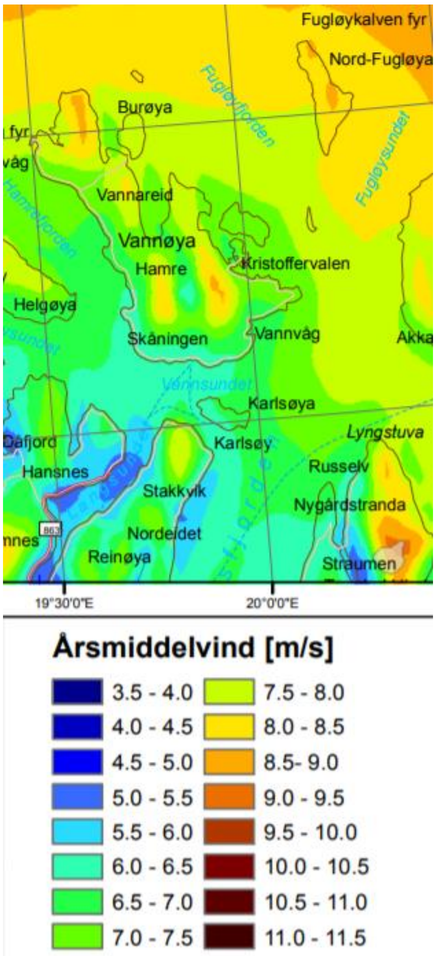

Figure 19: Yearly mean value of wind speed at Vannøya, Troms
NVE, Vindkart for Norge (2009). Retrieved from: https://www.nve.no/media/2462/vind_80m_kartbok1a_4140.pdf

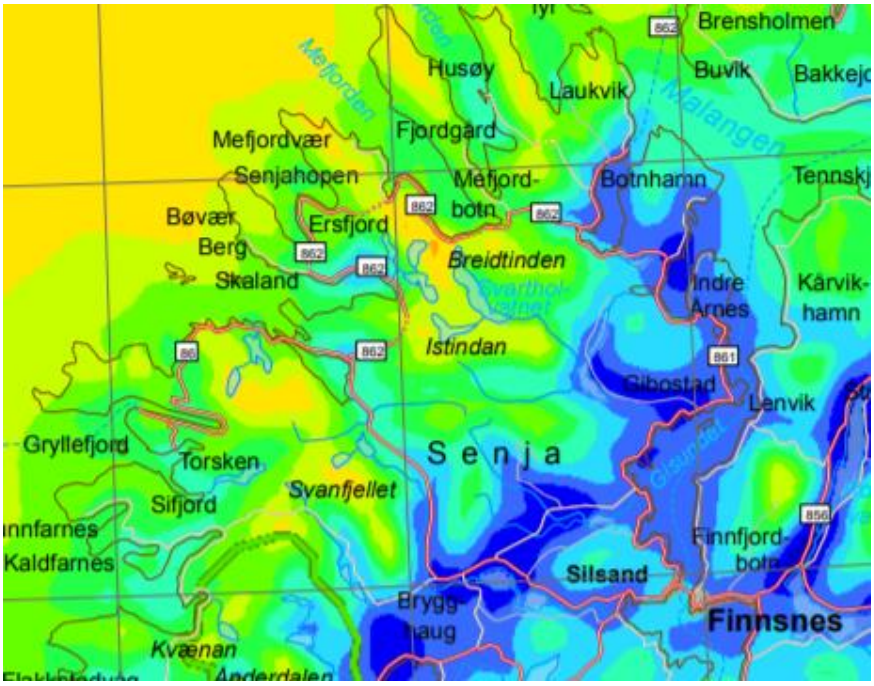

Figure 10: Yearly mean value of wind speed at Senja, Troms
NVE, Vindkart for Norge (2009). Retrieved from: https://www.nve.no/media/2462/vind_80m_kartbok1a_4140.pdf

As shown in Figure 19 and 20, wind speeds can become quite an issue on the outer parts of Senja and Vannøya, with mean values of around eight up to nine meters per second, and during storms, these values can become even higher. Because the need for inspections are usually higher during or after storms, it is important that one uses equipment that is capable of handling such situations.

Another factor that must be taken into consideration are the different military camps and establishments that are located in Troms, such as Skjold in Målselv and Setermoen in Bardu. To perform inspections in these kind of areas with helicopter requires special approval from the government and the military.

6 Discussion

UAVs as a tool is capable of performing most of the tasks that a helicopter is capable of doing. Because of the improvements in the state of the art, UAVs are capable of carrying cameras and sensors that can assure high quality results in both optical images and thermographic readings.

Additionally, inspections with UAVs will have a quicker response time compared to performing inspections with helicopters. Power companies will often not have their own helicopters to use as they see fit, and will have to rent helicopters, usually with a pilot as well since becoming a pilot for a helicopter is not something that many people will be able to do. With UAVs, it would be enough to have a mode of transportation to the inspection site, and someone to actually operate the UAV. Even though there are requirements one must fulfil to be able to operate a UAV, they are far less time consuming. Because of this, power companies could be able to have some of their own staff fulfil these requirements to avoid having to hire other qualified personnel from outside companies.

An obvious advantage the usage of UAVs have over the usage of helicopters is the fact that you mitigate a lot of risk for the human operator. With an experienced pilot, helicopter flights are generally very safe, but there is always the possibility of something happening which could have fatal consequences. UAVs eliminate most of that because they are unmanned, but could still be an issue in heavy populated areas if the operator loses control, and it falls to the ground, potentially hurting people nearby.

Another advantage that UAVs have over helicopters is that they are far more environmental friendly. There are UAVs which run on gasoline, but for the most part they use electrical power. In a society where the reductions of fossil fuels is very important, changing out helicopters for UAVs might be a good idea.

If we look at a specific model of UAV, in this case I will be using the DJI Phantom 4 as an example[12], and look at its specs. This is a quite small and lightweight UAV, with a high quality camera that potentially could be used in inspections. If we look at the specs, we see that it has a high maximum speed of 20 m/s (72km/h). This means that in theory, this type of

[12] https://www.dji.com/phantom-4/info#specs

UAV should be able to quickly fly between poles and perform inspections. The bad news is that they have a max flight time of approximately 28 minutes, which means that inspections over longer periods could be an issue. To prevent this from happening, it could be an idea to perform inspections of smaller areas and recharging them in between each inspection.

Unfortunately, there are many disadvantages to using UAVs. Especially in areas such as Troms and because of the total size of the transmission grid that Troms Kraft has to inspect every year. With around 3500 kilometres of power lines above ground to be inspected, a lot of effort must be made to assure this is done in a fast and efficient way. With the usage of helicopters, according to Troms Kraft, they would be able to perform basic power line inspection with a rate of approximately 35 kilometres of lines per hour, and even slower when performing top inspection. This is of course a very inexact value, as this will depend hugely on the surrounding environment and conditions. Even though 35 km/h is a lot slower than the maximum speed of the UAV, the fact that they can stay in the air for longer periods, makes it so that they would be able to inspect larger areas over a longer time span.

If we take a closer look on Figure 18, we can see that there are a lot of small islands in Troms, where many of them have power lines. Many of these places are scarcely populated, which means there is not always an easy way of transportation there. On top of that, the roads may not be in a great standard. To go there with UAVs to perform inspections would be a huge waste of time, unless there coincidentally was an operator in the surrounding area. Not only that, but some of the power lines may be located far away from roads, which could make it hard to actually get within operating range for a UAV. For these kind of inspections, it would be much wiser to use a helicopter and perform them all at once.

Another factor that is especially relevant in the areas by the sea. These areas often suffer harsher weather than many other places. Especially wind is a huge factor. Helicopters have been used in the Norwegian offshore industry for many years as transport between the mainland and the offshore platforms, and has proven that they can handle the conditions. UAVs on the other hand will have a harder time. If we again use the DJI Phantom 4 as an example, then we can see that the max wind speed it can handle is 10 m/s. Compared with Figure 19 and 20, we see that this could be an issue in the areas toward the sea.

During a year, Troms Kraft have a large portion of their expenses during the winter. The winter in Troms is long, and could last from October to as long as May. During the winter, there can be many vicious storms, which take a huge toll on the transmission grid. Because of this, power companies must always be alert to the potential damages that can be done. In addition to having quite cold and winters, it is also dark for longer periods, which will make performing inspections even harder. This is a challenge both for UAVs and helicopters as this will make it harder to navigate and actually see the details, and if not handled carefully, could lead to a collision with the power lines or poles. Because of the hardship of performing inspections during the winter, this should be kept to a minimum, or when there is an absolute necessity.

The military bases also provide another problem to the usage of UAVs. According to Norwegian law[13], unmanned aerial vehicles are not allowed to fly in the vicinity of military areas. (§ 54) This means that inspection in these kind of areas would be impossible to perform with UAVs. The regulations for flying helicopters in these kind of areas are strict as well, but can be done with approval from the Norwegian government.

[13] https://lovdata.no/dokument/SF/forskrift/2015-11-30-1404

7 Conclusion and suggestions for future work

UAVs have seen a lot of improvements over the last couple of years, and is more available than ever. With high quality equipment as well in the form of small cameras and even thermal sensors. They are capable of flying at high speeds with great manoeuvrability, which should make them ideal for inspection of power lines.

Unfortunately, there are a still many issues with UAVs that must be improved. As this technology is quite new to the common masses. There are not as many qualified operators as one perhaps would have liked, meaning a lot of work would be put on a few people. To incorporate UAVs in to the normal procedures for inspection of power lines, the best way would probably be if the power companies have employees who are already qualified to fly UAVs.

However, as mentioned before, power companies are obligated by the Norwegian law to perform inspections every year. Therefore, it is important that the methods they use are capable of performing that. In Troms unfortunately, that seems to be a quite far-fetched idea. Around larger human settlements, it would probably be a good idea to implement UAVs in some sort of way, but the maximum time it can spend in the air, its robustness and its lower range per inspection, makes it not suitable in areas scarcely populated.

Because of all the restrictions that has been mentioned, especially to range and low robustness, compared to helicopters, they should not and cannot fully replace helicopters as a tool used for inspection of power lines. Instead, they should act as a supplement to inspection by helicopter, where inspections closer to larger human settlements could be covered by UAVs.

For future work, it would be desirable to further improve the research on fully automatic UAV operations. This would greatly reduce the response time for inspection, and cut down on the man hours required.

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