MONITORING OF OVERHEAD LINES WITH AUTONOMOUS FLYING PLATFORMS

A. Claudi[1], C. Willim[2], R. Meyer[2], J. Lamprecht[3]
[1] Department of Power Engineering and High Voltage Technology, University Kassel, Germany
[2] E.ON Mitte AG, Kassel, Germany
[3] Aibotix GmbH, Kassel, Germany
*Email: aclaudi@uni-kassel.de

Abstract: The paper presents a method for the monitoring of MV and HV overhead lines with an autonomous flying video platform, equipped with multi spectral cameras that perform life line inspection recordings. For this research project a multicopter with six rotors was chosen. The platform is equipped with communication and video transmission links to obtain data and life-images during the flight. The navigation is controlled by GPS and different sensors to maintain a stable and defined position in the air, predefined flight tracks can be flown without human action. The Electromagnetic Interference (EMI) caused by corona, magnetic and electric fields can affect the radio control communication and influence the operation of sensors and thus the flight behaviour. Therefore extensive laboratory test have been performed to assure safe and stable operation. The paper shows first results from the on-going project with regard to image recordings, different spectral resolutions, tests of the prototype platform in a high voltage lab, and the first experiences with In-Field-Operations.

1 INTRODUCTION

Overhead lines have to be inspected in certain time intervals with regard to the integrity of the insulators, the conductor wires and the auxiliary hardware. The current visual line inspection practice of distribution and transmission overhead lines is performed typically via ground patrol with binoculars and in some cases by conventional helicopters. The visual inspection from ground is somehow limited due to the distance and perspective of the observer; the inspection with conventional helicopters is expensive, noisy and needs special trained pilots and low level flight permissions for the overhead line corridors. In case of observed damages or suspicious parts photos were taken in a distance of approximately 10m, together with geographical information. For closer analysis or repair the line has to be switched off and can be inspected by service personnel, alternatively more and more live maintenance is performed.

In the last years additional monitoring techniques for overhead lines have been developed. Optical, electrical and acoustic methods have been introduced. Recently inspection robots were introduced, which are clamped on the overhead line conductors or the earth wire [1-3]. They are able to inspect and measure different parameters. Additionally they can perform certain repairs on the line.

This paper describes a mobile flying system, serving as a camera and sensor platform, which is able to perform inspections and measurements in close vicinity to the overhead line (figure 1).

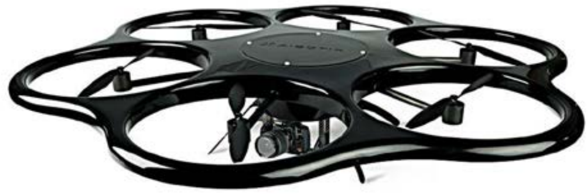

Figure 1: Flying sensor platform with camera

2 CONDITION MONITORING OF INSULATORS

The life time of insulators is in the range of 50 years and above. They account for only a small part of the capital cost of a transmission line but consume a large part of the maintenance cost. It is extremely important to correctly identify the condition of the insulator and to replace it before it fails and causes a power interruption.

Nowadays three different types of insulators are commonly used: porcelain, glass and, in the last decades, also composite insulators. Typical failures occur due to mechanical, electrical and environmental stress. Only a few failures can be detected by visual inspection. These are damages caused by vandalism and heavy contamination. To detect cracks and corrosion is more difficult and internal punctures can not be seen by this method.

Optical methods work with cameras and different spectral ranges and sensitivities. UV cameras, also called corona cameras, filter and amplify the UV part of corona and make it visible on a normal image. This method can be applied during day or night time. Depending on the location of the corona and the conditions, extended analysis has to be taken. Infra-Red Thermography monitors the surface temperature distribution along the insulator, which normally is in the range of some degrees. Any variation beyond this value is an indicator of defects [4]. However sun radiation and wind can disturb this method substantially.

Acoustical and electrical methods can also detect corona, this time by recording and locating the acoustic noise in the ultra-sonic range [5] or measuring the electromagnetic noise spectrum with high frequency radio receivers. In case of very long suspension insulators, a measurement of the linearity of the electric field along the string reveals shorted parts or internal defects. For this measurement the field probe has to be close to the insulator.

The described monitoring techniques for insulators can partially also be applied for the accessories of the line and the line conductor.

3 DESCRIPTION OF THE FLYING PLATFORM

The flying base is a lightweight CFRP housing ensuring propeller protection. The diameter is 1.05m; it is driven by totally 6 motors resulting in a maximum speed of 60km/h and a climb rate of 8m/s. The drive concept has an n-1 redundancy, so stable flight and landing is ensured with 5 working motors. The net weight is 2kg with a maximum payload of approx. 3kg. The total flight time is depending on the weight, a maximum flight time of around 50 minutes can be achieved. The platform is equipped with acceleration sensors and gyroscopes to obtain stable flight characteristics even in bad weather conditions. The global navigation is controlled via GPS and a compass sensor, the local navigation uses elements of artificial intelligence and image processing software combined with special sensors for the obstacle recognition system and the automatic landing system.

Although the platform can fly completely autonomous it can be controlled remotely via a standard Tablet PC. Special experience and knowledge in flying model aircrafts is not required. Take-off and landing are fully automated. The remote control for the manual flying of the platform is achieved with a secure 2.4 GHz digital link, which automatically switches between channels in the 2.4 GHz band with two independent multi- link receivers. The signals are coded with a 32bit key.

4 AUTOMATIC FLIGHT MODE

A fully autonomous flight mode is foreseen for the inspection of overhead lines. For this purpose the flight has to be planned in advance by loading the data into the flight computer. For this purpose the geographical overhead line course coordinates or simply satellite image maps are needed. With the selection of the waypoints the global navigation is fixed. After the start of the platform it will navigate to the subsequent waypoints with a predefined altitude and speed. Special events can be planned at each waypoint or between waypoints, e.g. taking photos, making measurements or the transfer into the local navigation mode. After reaching the last waypoint it will normally return to the start position. In case of emergencies or technical problems the platform will land and send a locating signal.

Figure 2: Approaching a 380kV Line

5 MANUAL FLIGHT MODE

In some cases a manual flight mode is preferred. This can happen if for example a damage at an insulator shall be investigated in detail. For that the platform is started just near the line and then manually flown to the object of interest. This can be done by visual control form ground or by using a live image which is sent directly to the ground station.

6 ON BOARD MONITORING SYSTEMS FOR OVERHEAD LINE MONITORING

At present the monitoring system consists of different cameras for taking images and making video streams. In the first flights, which have been performed recently, the questions of required image resolution, stability and vibration damping were addressed. For the time being the photos are taken and analysed later. This will be more automated in future. (See below). During the inspection the most importance is given to the integrity of the insulators, but also the line and the accessories (spacers, clamps, and torsion dampers) are observed from different angles and positions. In the following phases of the project this procedure will be more and more automated.

Phase 2: Automated flight along the line with fixed distance, controlled by image processing and recording of the phase conductors and insulators. This flight mode is called the “local navigation mode”. The platform is first approaching in the global mode. When the waypoint near the line is reached, the mode is switched to “local”, which means, that now the distance control and image recognition system will take the lead. The platform will take the relevant images which are then stored together with the geographical information. The analysis of the records is done after the flight.

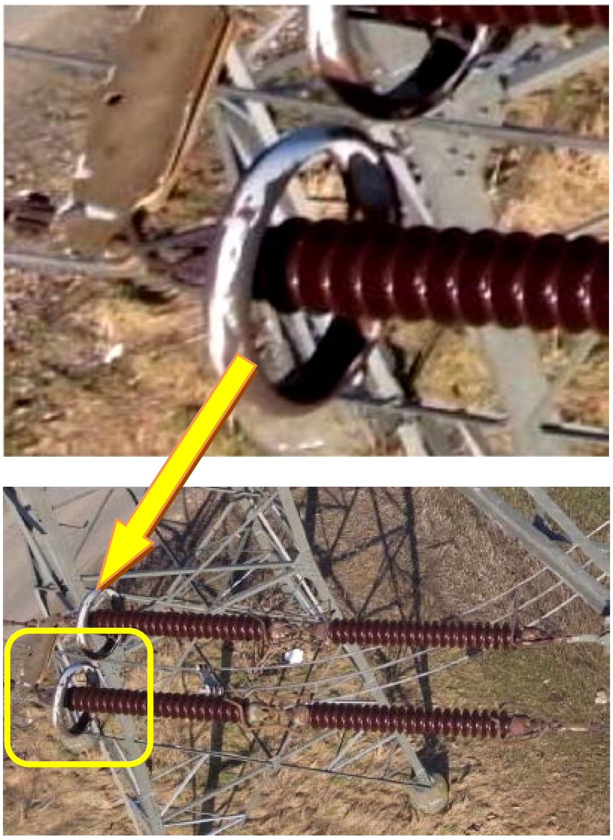

Figure 3: Typical in flight inspection image.

Phase 3: Enhancement of the system with multi-spectral detection methods: UV-sensors for the detection of partial discharges (PD), which are initiated by loose conductor strands or breaks in porcelain. IR-sensors for the detection of hot spots or overheated surfaces originating from corroded conductor joints or leakage currents on polluted insulators.

Phase 4: Same as phase 2 but with damage recognition system. The typically shapes of insulators, line conductors and accessories are simple geometric forms, which can be analysed easily to detect mechanical damages. Only suspicious parts are recorded and observed in detail to minimize the information. The relevant data and documentation of the damages are then recorded compatible with geographic information systems (GIS).

7 HIGH VOLTAGE IMMUNITY TESTS

The described platform is operated in a distance of some meters close to overhead lines with a maximum voltage of up to 420kV. The interference of electric and magnetic fields with nominal frequency and also transients, initiated by corona or switching events have to be taken into account.

Critical parts are the image recording, the transmission links to and from the platform and the GPS receiving signal. Particular attention was taken to the sensors of the flight control: the accelerometers, gyroscopes, the heading and the altitude pressure sensor.

For example the yaw rate gyro, which stabilizes the flight in all three dimensions, operates on the principle of an electrostatically driven resonator with a polysilicon sensing structure. The resulting Coriolis force during angular movement is transferred to a voltage by a capacitive pickoff [6]. The bandwidth of the element is in the range of some kHz. Although some internal signal conditioning against mechanical and electrical noise is taken it is questionable if the above described conditions can influence the operation of the system. Therefore extensive tests in the high voltage laboratory are performed before the platform is operated in the field.

For the simulation of the 50Hz magnetic field an arrangement is chosen with a single conductor in air, the current is adjusted to 1kA. The platform is positioned in a radial distance of 2m from the conductor in different angles. During the test, the system is in full flight operation, only secured by a vertical rope. All sensor signals are recorded via data link to the ground station.

The electric field test is undertaken with the same arrangement and a voltage of 300kV (line to earth). To simulate corona disturbance some needles are placed on the conductor.

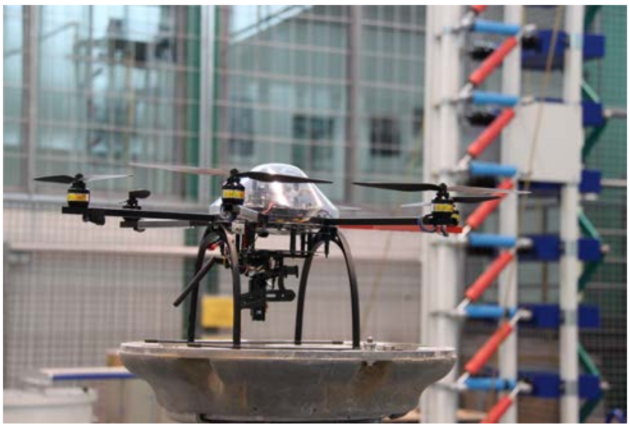

Figure 4: Multicopter in impulse test

The impulse tests are performed with a 1MV/50kJ impulse generator. Standard full and chopped lightning impulses and switching surges are generated. The “test object” is positioned close to the circuit which is formed by the generator, the impulse divider and the chopping gap (see figure 4)

8 BUSINESS ASPECTS

The advantages of the new monitoring method will be considered for medium voltage overhead lines. According to most utility rules these lines have to be checked in general every 4 years, more frequently in outstanding areas like forests, surrounding properties, crossings with railways, highways or other overhead lines. The aim of the visual inspection is to find faults like rottenness in wooden poles or corrosion in iron poles, broken line-insulators, switch-isolators and damaged conductors. Figure 5 shows an example.

This type of visual inspection is normally done by a minimum of two employees on a switched-off line. The advantage of this method is that small repairs can be done immediately on site.

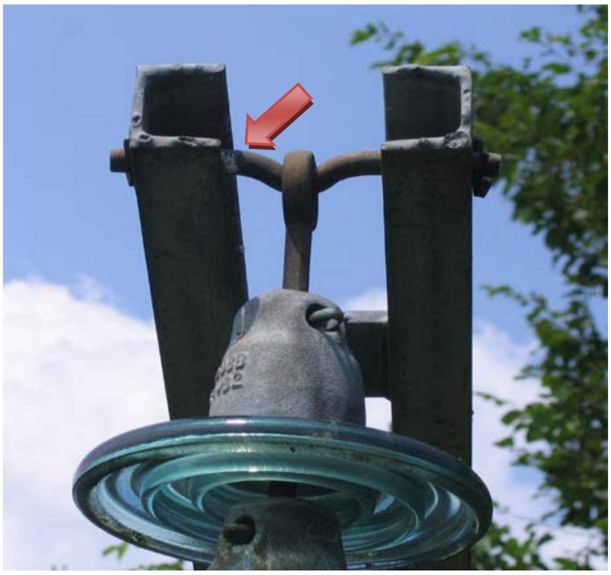

Figure 5: Arcing damage at a cross arm of a 20kV Line.

With the use of an autonomous flying platform the check-up can be done while the line is in service. Of course the wheatear conditions should be suitable, heavy rain, fog or stormy conditions should be avoided. The time for the inspection is substantially reduced. Furthermore better and more detailed examinations are achieved with the described technologies of multispectral images. Of course some time is needed for the analysis of the recordings. This can be reduced by automated evaluation reports. All in all the expenses should be substantially lower and the quality of the monitoring will be increased, leading to a better reliability and longer life-time of the overhead lines.

The multicopter platform can also be used in other application like monitoring of outdoor substations, gas-pipelines, PV- and wind plants, so that the capital employed can be shared between these tasks.

9 CONCLUSION

Visual Inspection of medium and high voltage overhead lines can be performed by flying platforms, which are able to take photos of the line elements with high resolution and from different viewing angles. The paper describes the capabilities of the developed system and shows which measures can be taken to improve the reliability and safety of overhead lines. The tests against electromagnetic interference in the high voltage laboratory are derived from worst case conditions in the field. In future the system will be enhanced by Uv and IR cameras and partial discharge sensors which allow e.g. the detection of cracks in the insulator. Beside cost reduction this new method offers new possibilities in modern asset management of MV and HV-overhead lines.

10 REFERENCES

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