CONDITION BASED RISK ASSESSMENT OF ELECTRICITY TOWERS USING HIGH RESOLUTION IMAGES FROM A HELICOPTER

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SUMMARY

This paper describes a high resolution image capture system developed by EA Technology for the purpose of performing detailed inspections of power line towers from a helicopter. The system aims to overcome many of the limitations associated with conventional inspection methods. It combines detailed photographic recording with the satellite-based Global Positioning System (GPS) and moving map displays to produce a permanent record of the condition of each tower inspected. The advantages of detailed information capture and archiving/auditing, coupled with ease, speed and a non-intrusive inspection process are demonstrated. The paper concludes by showing how the captured tower condition information is used both to initiate essential maintenance, and also to form the basis of a Condition Based Risk Management (CBRM) regime developed by EA Technology. This helps to predict remaining asset life span and assists network operators in determining their optimum investment strategy.

BACKGROUND

The routine inspection of electricity transmission towers is a costly and time consuming business, but a detailed assessment is essential in order to manage the assets effectively and maintain security of supply. Within the United Kingdom there are approximately 20,000km of steel tower transmission lines operating mainly at 132kV, 275kV and 400kV. The system described here has primarily been developed for use on the 132kV tower lines that are owned and operated by the Distribution Network Operators (DNOs), although there is no reason why it could not be used at the higher voltages if required.

There are several reasons why it is necessary to periodically inspect the towers. These include:

1. **Safety.** To make sure that no damage has occurred that could give rise to danger to persons or property in the vicinity.
2. **Legal.** The DNOs have a legal obligation under the Electricity Supply Regulations to periodically inspect their assets.
3. **Condition Assessment.** This is essential to enable planned maintenance to be carried out as required.
4. **Refurbishment.** This requires a more detailed inspection as a prerequisite to major overhaul on an ageing line or one that is undergoing reinforcement as a result of changes to the system configuration.

CONVENTIONAL INSPECTION METHODS

There are essentially three types of inspection that have traditionally been employed on steel tower power lines. These are foot patrols, climbing inspections and helicopter thermal inspections (using infrared cameras). The advantages and disadvantages of each of these methods are briefly described in the following subsections.

Foot Patrols

Foot patrols are useful for providing detailed information relating to features around the base of the tower, such as the footings, warning signs, anti-climb guards, vegetation growth, change of land use, and evidence of major defects or vandalism that is clearly visible. They are adequate to check safety features and fulfil legal requirements, but it is difficult to assess the condition of the equipment and fittings higher up the tower from the ground with any degree of accuracy, even when using binoculars. This is because of the poor vantage point coupled with the silhouette effect when looking upwards against the light of the sky.

Although a foot patrol can be performed relatively quickly and easily, little qualitative information is obtained relating to the condition of the insulators, fittings and steel members higher up the tower structure. One advantage of a foot patrol is the ability to perform a detailed visual inspection of the tower footings. There are also a number of specialist techniques that can be used to inspect tower footings, although these tend to be performed at much longer intervals than routine visual inspections. For example, the extent of underground corrosion may be assessed using polarisation resistance measurements, and in some instances, spot checks may be performed by excavating the tower footings to examine the metalwork and concrete structure for signs of degradation below ground level.

Climbing Inspections

Climbing inspections can provide greater detail regarding the condition of the structure and its fittings than a foot patrol, but at a significantly greater cost and inconvenience due to safety and electricity supply isolation requirements. On a dual-circuit tower it is usually necessary to de-energise and inspect each circuit separately. This means that it is necessary to return to the same tower on two separate occasions in order to climb and inspect each side. Any element of climbing involves a degree of risk to personnel safety that is best avoided if at all possible. The security of the network itself can also be exposed to a greater risk of supply interruption as a result of the isolation switching. In the event of a fault, it may not be possible to return the earthed circuit back into service quickly. By its very nature, any disturbance to the network provides the opportunity for errors or equipment malfunction to come to light, particularly if the remainder of the network is placed under a greater level of stress than it was previously subjected to in order to cope with the additional diverted load.

When climbing, there are also practical difficulties associated with the inspector producing a detailed record of the tower's condition in a suitable format that can be scrutinised later. As such, much valuable information may not be captured in the first instance, detracting from the overall value of the inspection process. For example, it is often useful to be able to compare and contrast the condition of two circuits that may have been inspected by different people and at different times, in order to prioritise refurbishment schedules. This is not easy when the judgement has to be based on a limited set of subjective notes, possibly produced after the inspection climbing has been completed. As a result, network operators are frequently forced to make decisions regarding maintenance and future investment strategy that are "less well informed" than they would like. If a decision is subsequently made to refurbish a particular tower line then, depending upon the condition of the line and the work to be done, a second more detailed survey may be called for. This is to record and quantify component count and configuration, in addition to the condition information established during the routine climbing inspection. This can mean revisiting each of the towers along the route and climbing them a second time to perform a more lengthy and time consuming inspection.

Conventional Helicopter Inspections

Thermal Camera Inspections. Inspections using a thermal camera are normally performed from a helicopter to look for "hot-spots". These inspections can be very effective for locating specific defects, such as poor connections, that heat up as a result of excessive I^2R losses. The results are normally recorded on video tape and a note made on an audio commentary as to which tower the defect relates to. Unless augmented with GPS position information, accurate tower identification relies on the navigational skills of the observer. The limited detail captured by the thermal camera means that the inspection can be performed relatively quickly in terms of flying speed. Reviewing the video tape afterwards is not too onerous a task because of the relatively small number of defects usually detected, and the fact that the defects are relatively easy to distinguish on the video. In addition, the inspector may already know which parts of the circuit are defective (and hence where to look on the video) from notes made during the flight. Other than detecting specific defects, thermal inspections provide no information relating to the general condition of the tower structure or its footings. Hence thermal inspections should be considered as a complementary technique rather than an alternative to visual inspection methods.

Daylight Video Inspections. Using a technique similar to the helicopter thermal inspection, it is possible to perform an inspection using a daylight video camera mounted on an inertially stablised camera platform in place of the infrared camera on board a helicopter. The inspection takes longer to perform than the thermal equivalent and produces copious amounts of video footage that can be very time consuming to review and analyse later. The resolution of the images produced, and hence the detail obtained, is limited by that of the video format used. Whilst the technique is used at higher voltages for inspecting the national transmission grid, it is generally not considered to be particularly cost effective for 132kV towers forming part of the distribution network because of the aforementioned limitations. Also, unlike digital still images, the format of the video output does not readily lend itself to rapid "point-and-click" image retrieval. Rapid image recall is considered essential if the images are to be used to maximum advantage within the DNOs, enabling the full benefit of the helicopter inspection to be realised.

EA TECHNOLOGY'S TOWER INSPECTION REGIME

EA Technology has many years of experience working with the UK DNOs, examining and developing new techniques to enhance aerial power line inspections under their Strategic Technology Programme (STP) [1-5]. The company has also offered a wide range of forensic failure investigation services within the electricity distribution industry for many years and has acquired a detailed practical and theoretical understanding of failure mechanisms relating to electrical distribution equipment during this period. More recently, ways of using this information to estimate future condition, performance and useful lifespan have been developed. The novelty of the tower inspection technique described here is the way in which it combines these three areas of expertise in response to a specific requirement driven by an understanding of the needs of the DNOs to produce a system and methodology tailored to their requirements. The result is not just a new type of field acquisition system, but a complete turnkey solution that encompasses asset condition analysis, life assessment and risk/failure estimation to meet the business needs of the DNOs both at an operational level and at a strategic level. Whilst the technique is applicable to other applications (e.g. wood pole circuits, overhead railway electrification systems etc), this paper will concentrate on the tower inspection application.

Figure 1 gives an overview of the method sequence in block diagram form. A brief overview of each of the functions is given in the following sections.

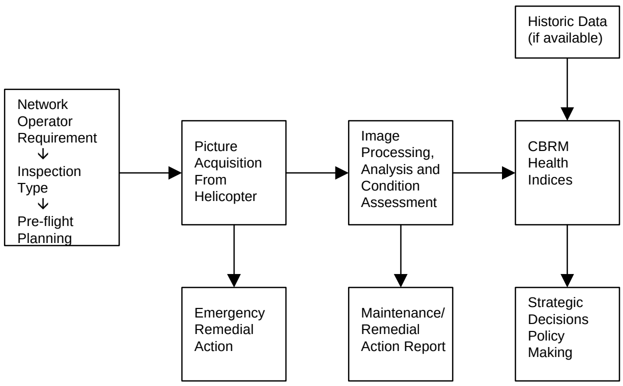

Figure 1. Overview Of Tower Inspection Methodology

Inspection Requirement and Pre-flight Planning

The process starts by identifying the specific inspection requirements with the DNO. The inspection type and criteria can vary both within an individual DNO, and from one DNO to another, depending upon their operational procedures and requirements. This determines the nature of the inspection as well as the format of its output. A certain amount of flight pre-planning is then performed to optimise camera angles, natural lighting and produce the most cost effective flight plan.

Picture Acquisition

The picture acquisition system employs a high resolution digital still camera. This is fitted with a high magnification telephoto lens that incorporates optical inertial stabilisation to reduce blur induced by helicopter motion and camera shake. Image resolution is typically greater than 3000x 2000 pixels which means that they will support digital image zooming on a PC during analysis to reveal greater detail on screen without pixelation as shown in Figure 2.

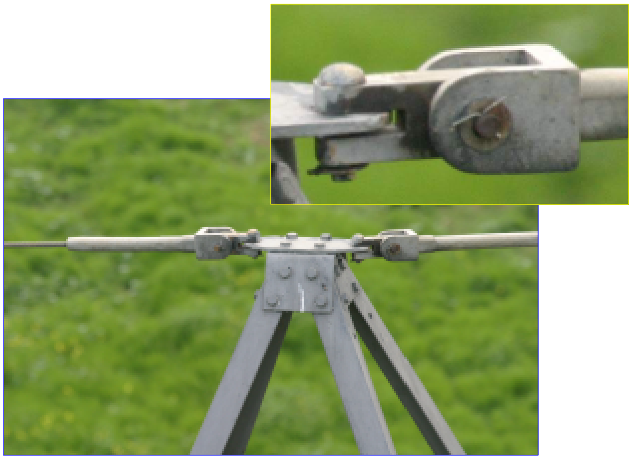

Figure 2. Use Of Digital Zooming To Examine Detail

Once the helicopter arrives on station, the camera is deployed through the open door by an operator wearing a safety harness (Figure 3). This give the greatest flexibility to capture the images of key tower features as determined by the inspection type and requirements. This is an important feature of the technique, as it effectively produces a significant degree of data reduction at the front-end of the process by only capturing information that is crucial to the requirements of the inspection. In contrast, video recording techniques can result in hours of unwanted footage that has to be filtered out afterwards. This is a time-consuming and laborious task.

Figure 3. Camera Deployment

The height and distance that the helicopter flies from the power line again depends upon the exact purpose of the inspection, but the system is capable or capturing significant detail from heights up to 100 – 170m if necessary. This means that flying over urban areas and livestock does not present a problem in terms of clearance or disturbance.

The camera connects to an image acquisition system within the helicopter that has been specially developed by EA Technology for performing aerial inspections of power line and railway networks (Figure 4). It houses a computer, hard disc drive, GPS and various video, audio and mapping equipment. The custom design allows the unit to be readily re-configured to meet the specific requirements of individual customer's inspection needs.

Figure 4. Image Acquisition System On Board A Helicopter.

In addition to providing a GPS-driven moving map display to aid tower location and positive identification from the air (Figure 5), it will also automatically record various time, date and positional (National Grid Map Reference) information for each photograph taken. It is totally self contained and independent of the helicopter systems so that it can be quickly fitted to almost any helicopter. It can also be deployed at the same time as a conventional visual or thermal inspections, and can be used to capture images of specific defects, wood poles, substations, tree encroachment, and land use if required, as well as tower images. The system has the capacity to store many thousands of images during a single inspection sortie, which will typically be of 2 – 3 hours duration including positioning. Flying speed is heavily dependant upon the level of detail (i.e. number of images) required per tower. For a simple inspection requiring say three images per tower, speeds of up to 40 knots can be achieved. Highly detailed inspections requiring say 20 images of each side of each tower will reduce the speed significantly, but will still be much faster than conventional climbing methods.

Figure 5. GPS-driven Moving Map Display To Aid Asset Identification

Emergency Remedial Action

If during the course of the helicopter inspection, a severe defect is spotted that could expose a member of the public to danger, the details will initially be telephoned through to the DNO network control centre as soon as practicable after landing. Subsequently, one or more images can be emailed via a terrestrial cellular telephone link (or a satellite telephone link) to the control centre to assist them in deciding what emergency remedial action they should take.

Post Inspection Image Processing, Analysis And Condition Assessment

Following their acquisition, the images are sorted and their details held within a large database incorporating hyperlinks to quickly access the images for viewing. An information label is embedded across the top of each image. Typically this will include the circuit/tower identification number, image file name, time, date, GPS position, and the position of the image on the tower. For each tower, the database also has data entry fields for each of the condition assessment criteria required for the inspection type. During the analysis phase, experienced assessors view the available images in order to complete the condition assessment fields for each tower inspected. The level of detail recorded is chosen to suit the DNO's requirements, but will typically include a range of condition records for each of the following aspects:

- Tower body/arms
- Earth fittings
- Tower base
- Insulator strings and associated fittings
- Conductors
- Land use
- Vegetation
- Warning signs and anti-climb guards
- General aspects

The database is set up in such a way as to automate the image processing and analysis as much as possible in order to minimise the time taken by the assessor. The tower condition information is then used in two ways. Firstly a Maintenance/Remedial Action survey report is produced. Secondly, the information is processed further to form the basis of a Condition Based Risk Management (CBRM) analysis. Both of these inspection outputs will now be described in more detail.

Maintenance/Remedial Action Report

This is a written report of a more conventional format and will generally be produced on a circuit by circuit basis. It gives an overview of the general condition of the towers comprising the circuit and makes recommendations for any remedial action/maintenance work that is considered necessary. Specific defects are highlighted and supported by images showing examples of the defects and equipment type. The report is primarily intended for use by engineers within the DNO's maintenance department to assist them in identifying and implementing any corrective action deemed necessary.

The written report is accompanied by a DVD-ROM containing a copy of the condition assessment database for the circuit plus all the photographic images, which can be accessed directly from within the database via hyperlinks. This allows the overhead line engineers within the DNO to view the details and pictures for individual towers when planning their maintenance work, avoiding the need for site visits. All the tower images can also be imported into a corporate asset management database if required, thereby making them available throughout the company for any other purposes, such as auditing the quality of contract work, tree cutting or wayleave planning for example. The inspection results and images can also be archived enabling the DNO to demonstrate compliance with regulatory and legal requirements.

Figure 6. Typical High Resolution Inspection Image

Condition Based Risk Management (CBRM)

CBRM is a process developed by EA Technology to assist DNOs in making asset management planning decisions at a strategic level, rather than at a circuit level. It involves combining all available practical and theoretical knowledge and experience of assets to define current condition and then uses this to estimate future condition and performance. In addition it provides a sound engineering basis for evaluating risks and benefits of potential investment strategies. Over a period of several years, EA Technology has developed a working methodology and has practical experience of successful applications.

The CBRM process is described fully by Hughes [6]. The basic principle involves deriving health indices for the different asset groups under consideration, using all available information relating to the assets' condition. Using knowledge of asset degradation/failure modes, the current Probability Of Failure (POF) is then estimated. Over a period of time, the health index rankings are then fine tuned by calibration against a standard POF curve using an iterative process incorporating any additional condition/degradation information that becomes available. The current asset condition information is then used to derive the future condition and future POF looking forward. This can then be used to evaluate different intervention strategies against future POF. Finally, an overall risk model is constructed that combines the POF with the asset's criticality and consequences of failure. This allows the DNO to examine and quantify the effects of different investment strategies across different parts of the network and model the impact they will have in the future.

Separate health indices are calculated for tower structures and conductors/fittings. For economic reasons, the tower structure health index is calibrated against need for painting/refurbishment rather than POF. This is due to the very low incidence of tower failure. The individual health indices for each tower are combined to produce a health index for each circuit. These are then fed into an overall risk model that takes into account other risk factors associated with the circuit that are unrelated to its condition (e.g. the number of customers connected, or its criticality to network security). The overall risk model then enables the implications of different investment strategies to be compared on a circuit by circuit basis.

CBRM relies on utilising existing information to derive the initial health index values, and has been successfully applied to all major asset groups including overhead lines. However the nature, consistency, and form of condition information, for overhead lines in particular, is a significant issue. This means that generating health indices can be a very labour intensive exercise. The condition information gathered from helicopter photographic inspections provides an ideal method to collect complete, consistent, and reliable information in a form that can be readily used to derive health indices. Adopting the high resolution photographic inspection regime described in this paper will lead to accurate health indices that can be derived routinely. This will result in much more effective strategic asset management decision making within the network operating companies.

CONCLUSIONS

The inspection of electricity transmission towers is a costly but essential activity that must be undertaken by electricity utilities worldwide. Within this paper, the advantages and disadvantages of traditional inspection methods employed within the UK have been briefly discussed. A new methodology for inspecting tower lines has been introduced that makes use of high resolution photographic images taken from a helicopter. This offers a turnkey solution to DNOs by providing detailed circuit condition reports as well as an aid to higher-level strategic planning based on sound engineering decisions. The image acquisition process not only overcomes many of the limitations associated with traditional inspection methods, but offers significant added value to the output from the helicopter inspection in terms of the detail and quality of the condition assessment information obtained. This information, together with the images, can readily be archived/referenced to provide a permanent record for regulatory/legal purposes as well as being utilised for other asset management purposes.

The paper concludes by showing how the improved quality of the information gathered is ideally suited to a Condition Based Risk Management regime developed by EA Technology for strategic asset management and investment planning. The image acquisition system has been successfully deployed in the UK on a number of projects, including a survey of over 2000 132kV steel towers during the summer of 2003. EA Technology's CBRM methodology has been successfully applied within a number of UK DNOs as a practical means of meeting strategic objectives and has been well received by the UK electricity industry regulator OFGEM. More recently the high resolution photography inspection technique has been combined with the complimentary CBRM process to produce a very powerful method for managing electricity distribution tower assets and optimising investment decisions.

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