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Application of Advanced Condition Assessment and Asset Management Techniques on Steel Tower Overhead Line Electricity Networks

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SUMMARY

Through example, this paper discusses how a clear "Line of Sight" has been established throughout an asset management process for overhead line steel towers. Several condition assessment methods are presented, each with an emphasis on collecting consistent, accurate condition information suitable to gain maximum benefit from Condition Based Risk Management, itself a process which allows companies to use current asset information to justify and optimize future intervention expenditure. The example presented here demonstrates how the processes have been integrated within Northern Powergrid, a major UK Distribution Network Operator, as key components within their adopted inspection and refurbishment strategy for overhead lines.

KEYWORDS:

Condition, Assessment
Asset, Management
Quality
Overhead Lines

1 Introduction

Owners/operators of the UK electricity overhead line transmission and distribution systems are challenged with the management of a mostly aging network. Maintaining up to date records of the condition of such assets is also a challenge given the large numbers of assets and the distance over which they are dispersed geographically.

Through example, this paper discusses how a clear "Line of Sight" has been established from the initial asset identification stage through to delivery of specific capital solutions. Various condition assessment techniques are covered with a focus on Condition Based Risk Management (CBRM) as a platform for consolidating asset risk and its use as a prominent tool within the overall decision making process.

CBRM has been widely established as a powerful process that enables companies to use current asset information, engineering knowledge and practical experience to define future condition, performance and risk for network assets on a comparable basis. The development and application of CBRM can be charted by reference to several published papers [1, 2, 3, 4, 5].

CBRM is a tool that can be applied to a wide range of assets, and has been demonstrated to bring real value as an approach for justifying and optimizing future spending. CBRM can be applied and used with the most basic of condition data as a starting point; however, it can be used with increasing effectiveness with better quality condition information as an input to the condition models.

Specifically this paper describes how the complete process has been applied within Northern Powergrid, a major UK Distribution Network Operator (DNO), providing a key input into the Northern Powergrid condition and risk based refurbishment/rebuild strategy for all steel tower overhead lines.

In particular, it is used as part of the decision making process for overhead tower line refurbishment programs allowing individual components to be first assessed and then a collective economic assessment to be undertaken on an individual circuit basis. Forecast intervention profiles (by planning for a particular level of intervention on a circuit by circuit basis) for the medium and longer term can be established based on the individualized analysis offered by CBRM. The selection of candidates for any additional intrusive and non-intrusive assessments can be informed to offer efficiencies in the overall program through the effective targeting and scoping of these additional assessment requirements.

2 Requirements of a major Distribution Network Operator

At Northern Powergrid a condition and risk based refurbishment/rebuild strategy (Figure 1) for all overhead lines is adopted which encompasses condition assessments appropriate to each voltage level and structure type.

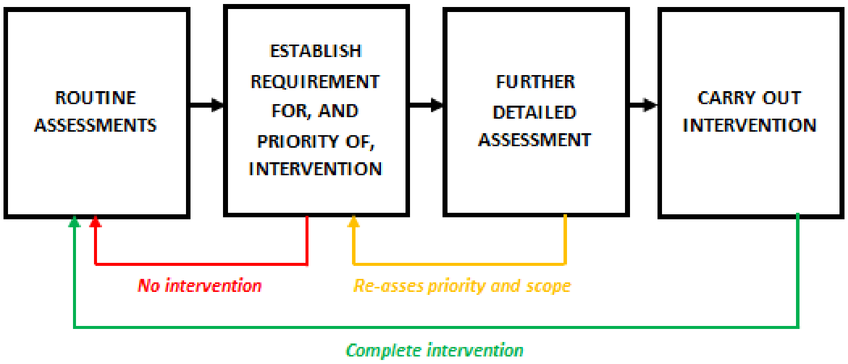

Figure 1: Inspection/refurbishment strategy adopted.

Individual components are assessed for replacement or refurbishment, with a collective economic assessment then undertaken on an individual circuit basis, typically using:

- **Health indices (HI)** - considers factors relating probability of failure (proximity to end of life); and

- **Criticality indices** - consider the consequences of failure of an asset in each of the following four areas; network performance, safety, environmental and financial (repair/replacement).

These indices offer a means of combining information to give a comparable measure of condition and risk for individual assets. These quantifiable metrics allow the overall risk level (derived from the combination of health and criticality indices) to be defined both now and in future years by applying degradation algorithms appropriate to each individual asset. This is useful for predicting remaining service life and probability of failure (POF). In doing so, it provides a sound engineering basis for determining far more effective intervention strategies based on risk rather than traditional time scheduled programs (i.e. any refurbishment is performed where and when it is needed, rather than simply because an arbitrary time period has elapsed). The methodology is well developed and has a proven track record of successful application in practice.

More specifically, EHV and 132kV overhead electricity steel tower lines are managed on an individual circuit basis in Northern Powergrid due to the population size and asset criticality. The key initial input into these indices is condition data initially gathered from a program of helicopter inspections encompassing the capture of high resolution digital images, as described within this paper.

This data is verified by additional intrusive and non-intrusive assessments, in addition to operational knowledge from experienced field staff, on an individual circuit basis. Again some of these assessment techniques are described within this paper. Importantly it is the result of the initial routine condition assessment which informs the scope, identification and prioritization of the additional assessments.

Northern Powergrid is therefore well positioned to determine forecast intervention plans on an individual circuit basis. The longer term Northern Powergrid investment portfolio is characterized by individual circuits with initial scopes of work established at a major component level, utilizing well founded planning assumptions where necessary. Dependent on the results of the initial assessments, circuits would usually require one of the following types of intervention; remedial only, tower refurbishment, line refurbishment (excluding of conductor), line refurbishment (including of conductor) or replacement with underground cable.

It is the quality of the underlying assessments that facilitates this bottom up plan development. Referring to the strategy presented in Figure 1, this paper presents three such assessment methods as follows:

Routine Assessments:

- Detailed condition assessment using high resolution aerial photography

Further Detailed Assessments:

- Non-intrusive tower foundation condition assessment
- Overhead line conductor sampling assessment

3 High-resolution aerial photography

A key method of condition assessment is an advanced aerial inspection service [6, 7] that offers supplementary assessment results to the more traditional walking or climbing inspections, while avoiding the requirement for electrical isolation or switching beforehand. It is a visual inspection method for collecting detailed condition information of the overhead line assets, and to date has been applied to over 35,000 steel lattice electricity towers across the UK. This includes all 5,700 towers in Northern Powergrid's network, the majority of which were inspected in 2010 – 2011.

Specialized digital still photography techniques are used to capture critical condition information photographically from a helicopter. The helicopter crew includes a pilot, an observer in the front of the helicopter, and a cameraman deployed out of the rear side door of the aircraft. The photographs are then cataloged and linked to an assessment database, which is populated with condition information by performing a detailed analysis of the assets using the images. The condition information is then presented to the asset owners in the form of a condition matrix, which is color coded to highlight areas which require attention (Figure 2).

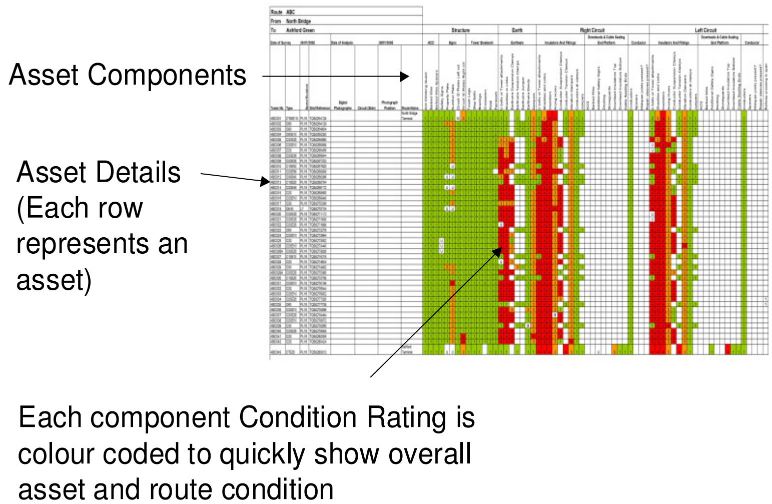

Figure 2: Condition Assessment Results.

The inspection service records information relating to safety, such as condition of anti-climbing devices, safety and operational signage, flag key condition, etc. However the main focus of the inspection is to obtain condition information on the tower steelwork, insulators, insulator fittings and earth wire fittings. Mid-span images of conductors are generally not taken since it would normally result in large numbers of images, and is time consuming for little benefit. However, damage that is identified by the helicopter observer would be recorded and photographed. A close inspection of conductor condition is also possible immediately adjacent to the insulators and earth wire fittings from the high-resolution images obtained. The condition of the asset is recorded by assessing a series of condition points, using a condition rating (CR) system of 1 – 4, with CR1 being as new condition. The criteria for the selection of the individual condition points has been driven by the requirements for HIs and CBRM, i.e. the questions asked were very much "what information do we need for CBRM" rather than "what can CBRM do with this information". As such, the inspection methodology has been honed to maximize the usefulness of the information with respect to the higher level asset management of the structures.

In the methodology, this starts with the photography itself. The cameraman and observer in the helicopter are engineers (as opposed to mere "cameramen") who understand what information they are trying to obtain. This brings into play the concept of "Line of Sight" right from the beginning of the process, which remains throughout. The images are carefully obtained, cataloged and referenced with the end goal in mind.

The condition points and condition assessment criteria are agreed and customized for each individual client; however the concept of collecting condition information for use with CBRM will remain. For steel towers, up to seven individual health indices are calculated as follows: tower steelwork; left circuit fittings; left circuit conductors; right circuit fittings; right circuit conductors; earth wire fittings and earth wire conductors. Most of these health index values are calibrated against POF, since the components will require replacement rather than refurbishment at end of life. Tower steelwork however is calibrated against the economic cost of refurbishment, and is modelled on the costs of replacing the protective coating on the steel tower. If painted regularly, the life of a steel tower can be extended almost indefinitely. Painting at the optimum time will result in the maximum life gained from the previous paint system coupled with minimal surface preparation required before painting. Painting too late will often result in significant additional surface preparation, and in severe cases, replacement of sections of steelwork.

Figure 3: Steelwork and degradation of protective coating.

Similarly, the insulator and earth wire fittings (Figure 4) are assessed relative to degradation issues which lead to known failure modes, such as severe rust and evidence of wear. The highest condition rating requires the presence of severe wear, not just rust. Since there is very little movement in tension fittings, wear is very uncommon, therefore the highest condition rating is only likely to be used for suspension fittings where wear is more of an issue. Insulators, whether glass, porcelain cap-and-pin or composite, are also scored relative to evidence of developing failure modes.

The major advantage of being able to use a helicopter to perform this assessment work is the ability to inspect a large number of towers in a short timeframe. The percentage inspected in a given program varies from one DNO to another, but is typically either 10% of the network per annum (as part of an ongoing program), or 50% of the network or even 100% of the network over a 6, 18 or 24 month period. The digital still photography methodology allows approximately 95% of all steel towers on a network to be assessed accurately by helicopter. The remaining towers can be inspected using supplementary ground photography or Unmanned Aerial Vehicle (UAV) inspections, which can be carried out rapidly on a small scale.

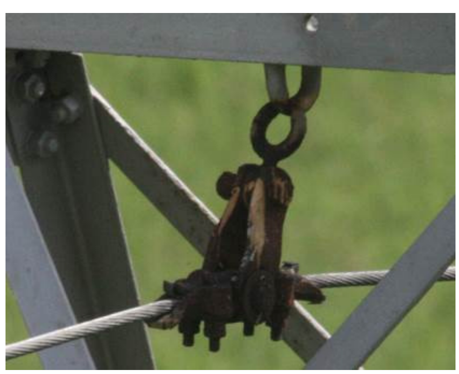

Figure 4: Severely degraded earth wire fitting.

The ability to inspect a large number of assets quickly provides an accurate "snapshot" of the condition of the assets across the network. With a consistent inspection approach applied to all of them, the CBRM methodology can then be used to model a fair comparison of the various assets and model future degradation, as input to the decision making process for future refurbishment.

The condition results are presented in a format which makes the information easily accessible (Figure 2). Hyperlinks are built into the spreadsheet allowing quick access to all images used to perform the assessment. This means that the scoring can be reviewed with ease, for both quality control and auditability.

4 Non-intrusive tower foundation assessment

The difficulties associated with inspecting tower foundations have meant that it is rarely done. In addition, overhead line asset records within DNOs are often only partially complete, particularly for the structure foundations. This lack of information is becoming increasingly problematic, both due to the risk of failure (which, although rare, has high consequences) and also in terms of being able to accurately calculate a foundation's loading capacity.

Traditionally, the foundations can be excavated to allow inspections to take place. However, there are some significant disadvantages with excavating foundations (Figure 5). Excavations are disruptive to both the surrounding land (with resultant right of way issues) and the foundations themselves, meaning that it is generally only practical to excavate a single leg per inspection, and this is typically only done on a small selection of towers.

Figure 5: Excavations can be disruptive.

Non-intrusive inspections [8] have the advantage that they can be performed on every tower leg, cause minimal disruption to the surrounding land and all assessments are carried out from ground level. The results can be used to determine the tower legs most likely to have suffered degradation, and these legs can be targeted for excavations for a closer inspection and potential remedial work. Potentially therefore, this represents a consistent approach that can be applied to all tower foundations across a network (Table 1).

Measurement	*Purpose*
Transient Dynamic Response (TDR)	Measure depth of concrete foundation, or depth to nearest anomaly(crack)
Polarization Resistance	Measure the rate of any ongoing corrosion of steelwork below ground
Soil Chemistry	Measure pH and oxygen level of surrounding soil (affects corrosion rate)

Soil Resistivity	Measure soil resistance (affects corrosion rate)

Table 1: Measurements taken during non-intrusive inspections.

Assessment of the soil conditions allows an additional assessment to be made, by identifying the towers at most risk of significant corrosion damage in the future. This information is then combined with the non-intrusive condition information using a scoring and weighting system, and a final condition rating obtained. A CR4 will be assigned if there is evidence of severe degradation or evidence of moderate to severe degradation where the tower leg is situated in an environment conducive to more rapid degradation. These legs will be highlighted for excavation inspections, and the condition ratings adjusted if required.

A health index can then be calculated for the tower foundations. Inputs can be set for construction type (if known) and approximate age. An environmental factor can be derived from the soil measurements, and the various results combined with weighted scores, resulting in a HI. The final HI will also include information from excavations and/or repairs, and the presence of effective sacrificial anodes.

6 Conclusions

Through example this paper discusses how a clear "Line of Sight" has been established from the initial asset identification stage through to delivery of specific capital solutions for a particular asset category. Various condition assessments techniques are covered with a focus on Condition Based Risk Management (CBRM) as a platform for consolidating asset risk and its use as a prominent tool within the overall decision making process.

CBRM has been widely established as a powerful process that enables companies to use current asset information, engineering knowledge and practical experience to define future condition, performance and risk for network assets on a comparable basis. It features in a number of key Northern Powergrid business processes including:

- Initial capital scheme identification and prioritization
- The ability to present a future profile with and without intervention provides a useful tool for the development and validation of capital investment plan
- Regulatory submissions
- Risk management process for major substations
- Discrete investment appraisals
- Asset replacement / refurbishment strategy
- Refinement of field data inputs – to reduce subjectivity during inspections

This paper has described how EHV and 132kV overhead power lines are managed on an individual circuit basis in Northern Powergrid using CBRM. It is important for condition assessment information to be both current and comparable across a network or asset group. Therefore the key input into these indices is the condition data initially gathered from a program of helicopter inspections encompassing the capture of high resolution digital images, as described in this paper.

This data is verified by additional intrusive and non-intrusive assessments, in addition to operational knowledge from experienced field staff, on an individual circuit basis. Importantly it is the result of the initial routine detailed condition assessment which informs the scope, identification and prioritization of the additional assessments.

Northern Powergrid is therefore well positioned to determine forecast intervention plans on an individual feeder basis. The longer term Northern Powergrid investment portfolio is characterized by individual feeders with initial scopes of work established at a major component level, utilizing well founded planning assumptions where necessary, possible due to the robustness of the underlying data inputs.

The sensitivity of the forward plan to these planning assumptions is magnified for the larger value asset bases due to the overall costs of the various solutions. Replacing conductors during a tower line refurbishment type scheme, for example, can double the cost of the solution which would usually be in the order of several hundred thousand dollars. The importance of the quality of the underlying data inputs and follow up assessments is therefore essential with respect to the overall efficiency of the delivery pipeline. This underlines the success of the work presented here.

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