PROBABILISTIC PLANNING OF OVERHEAD LINE SUPPORT MAINTENANCE

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SUMMARY

At many network operators, a quite substantial amount of money is flowing into the maintenance of overhead line supports. This maintenance is carried out in order to avoid more expensive maintenance in the future as well as to reduce the risk of a tower fall or collapse due to deterioration of a tower’s structure.

The paper focuses on the conservation of steel towers, but the proposed methods and practices may with little modification be applicable to wood and concrete supports as well. The approach to condition based tower painting adopted by Essent Netwerk B.V. is described and a probabilistic maintenance planning approach is discussed.

INTRODUCTION

With the restructuring of the electricity sector at present going on in many countries, the transmission and distribution networks tend to be considered a natural monopoly. Therefore, regulating bodies are created in order to prevent network operators from abusing their monopoly power. These protect customers that depend on the networks for the supply of a vital resource. Although the regulatory approaches adopted by these bodies vary, their aim is to increase in some way or the other the effectiveness and efficiency of the network operators. The goal is to achieve both lower tariffs as well as an increase in supply reliability for customers connected to the network.

It can be easily imagined that the increasing political and public expectations, together with the income decreases being faced by network operators, lead to a pressure on cost. This in turn leads to the necessity to be able to justify as many expenditures as possible either by proving their positive contribution to the company’s business values, or by showing that postponement would lead to higher expenditures in the future. For the latter, a Net Present Value (NPV) calculation should of course be used to compare expenditures at different moments in time in a correct way.

Many network operators spend a quite substantial amount of money on the maintenance of overhead line supports. Therefore, taking into account the above mentioned developments, overhead line support maintenance is an example of an expenditure that is worth to be carefully investigated in order to see whether a further optimisation would be possible.

In this paper, the approach towards condition based steel tower conservation as practised by Essent Netwerk B.V. is presented. First, the inspection approach used to determine the condition of the tower coating is discussed. Then, it is described how notwithstanding the condition based approach towards tower painting, it is nevertheless possible to investigate the required budget to keep a population of towers in good condition, or, put the other way round, how the condition of the coating of a tower population will develop over time when the budget is fixed. In figure 1, two tower types occurring frequently at Essent Netwerk B.V. are depicted.

MAINTENANCE APPROACHES

Many installations and devices require maintenance in order to keep them functioning appropriately. Normally, three different types of maintenance are distinguished, namely [1,2]:

- Corrective maintenance: the installation is repaired after failure (e.g. the front window or the exhaust of a car, that are normally repaired or exchanged after having failed).
- Time based or periodical maintenance: the installation is maintained after a certain interval. This interval may be purely time based, or based on the intensity of use (e.g. regular maintenance of a car, such as oil and spark plug exchange, that is based either on mileage or on time since last treatment).
- Condition based maintenance: the installation is maintained based on its observed condition (e.g. a car's tyres, whose condition is determined by the remaining tread).

Time based and condition based maintenance are both preventive maintenance, as they aim at preventing failure, rather than fixing it, as is done in case of corrective maintenance. The choice of a maintenance regime for a device or installation depends on various factors. When the
consequences of failure of a device are relatively limited (i.e. failure cost is low) and when it is not practically feasible to observe an indicator to monitor its condition (either because the underlying physical mechanisms do not allow this or because the associated cost becomes too high in comparison with failure cost), corrective maintenance is most suitable. When the consequences of failure are severe but it is not feasible to monitor the condition of a device (again either because the underlying physical mechanisms do not allow this or because the associated cost becomes too high in comparison with the cost of the maintenance itself), time based maintenance should be applied. Finally, when monitoring the condition of a device is feasible (which means that it is physically possible and less costly than both failure and possibly superfluous time based maintenance), condition based maintenance should be applied.

It should be noted that it is important to take the appropriate scope for determining the “cost of failure”, i.e. not only the cost of the component(s) to be replaced, but also in some way or the other the cost of the indirect consequences, such as production losses due to plant unavailability or endangering of personal safety.

As can be concluded from the above, despite the general trend towards condition based maintenance, it is definitely not the optimal approach in all cases. However, it may indeed bring considerable savings when applied sensitively. High voltage tower painting is considered an area where condition based maintenance can be fruitfully applied, because:

- As argued in the next section, the condition of the coating can be relatively accurately determined.
- The cost associated with determining the condition of the coating is relatively low when compared to the cost of both superfluous maintenance, as well as the cost of failure.

**TOWER INSPECTION**

**Condition assessment approach requirements**

As discussed above, a suitable approach towards condition assessment is crucial for successful application of condition based maintenance. In order for a condition assessment approach to make sense, it must have the following properties:

- **Reflectivity**: the observed characteristic(s) form a reliable indicator for the condition of the equipment of which the condition is to be assessed.
- **Objectivity**: the assessment of the condition of a given installation by different people yields similar results
- **Reproducibility**: a repeated assessment of the condition of the same installation or an assessment of different installations which are in similar condition should yield similar results

In the development of an inspection approach for high voltage tower coating at Essent Netwerk B.V. that will be discussed now, these criteria have been taken into account.

**Inspection criteria**

The following aspects of coating condition are taken into account in the inspection approach used by Essent Netwerk B.V.:

- **General condition of the coating**
- **Coating thickness**

For each inspected tower, an inspection form is filled out for which four locations are inspected. The inspected locations should be spread over the tower and are indicated on the inspection form in schematic representation of the tower. An example is indicated in figure 2. The number of towers being inspected on a route is equal to the square root of the total number of towers.

On the inspection form, the general condition of the paint is characterized by the visual appearance (dirt, algae, bird droppings, etc.), paint detachment, the occurrence of bar edge defects (as bar edges tend to be weak spots in the paint layer) and hidden corrosion below the coating. Each of these aspects is scored on a scale from 0 (very bad) to 5 (perfect). For every characteristic, the meaning of the scores is indicated qualitatively on the form, so that the inspectors continuously have at hand the meaning of the scores. This is done in order to maximize objectivity and reproducibility and to ease further processing of the results [3, 4].

For scoring the extent of paint detachment on the scale from 0 to 5, the following approach is used. A lattice is curved in the coating, adhesive tape is stuck on it and the result after tearing off the tape is observed. To objectify the assignment of a score to an inspector’s observation, the correspondence between the observation and the score is depicted graphically on the inspection form, as depicted in table 1. The coating thickness is measured using a (digital) coating thickness gauge. At each inspection location, four bars are selected for measuring the coating thickness, preferably horizontal, vertical and diagonal bars. From each bar, eight measurements are taken. All measurement results are recorded in the predefined tables on the inspection form for further analysis.
### Table 1. Correspondence between observed paint detachment and score on a scale from 0 to 5

<table>
<thead>
<tr>
<th>Score</th>
<th>Extent of detachment [%]</th>
<th>Appearance</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>&gt;65</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>&gt;35-65</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>&gt;15-35</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>&gt;5-15</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>&gt;0-5</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>

#### Interpretation of inspection results

After collection of the inspection results, they must be interpreted in order to evaluate the condition of the coating. The items scored on the scale from 0 to 5 (visual appearance, detachment, corrosion and edge defects) are weighed and then added. Based on the resulting score, it is decided whether the visual appearance is such that treatment of the towers would be necessary or whether it can be postponed. If no maintenance needs to be carried out, the score is also used to determine when the next inspection should be carried out.

The general judgement on the coating thickness is formed by plotting a cumulative percent frequency distribution of the coating thickness measurements (4*4*8=128 measurements per inspected tower), as shown in figure 3. By defining a certain coating thickness and a value for the percentage of measurements that is accepted to have a thinner coating, it can be decided whether the coating thickness is such that treatment would be necessary. Further, by assuming an annual decrease in coating thickness, it can be investigated how the coating thickness will develop over time and when treatment would be necessary if not needed presently yet.

It should be noticed that both the visual appearance as well as the coating thickness can independently lead to a need for maintenance of the coating. To determine the exact actions to be undertaken, not only the inspection results, but also the type of steel of the tower, the paint used for earlier treatments, as well as the future need for the specific line should be taken into account. The reasons for this are that not all types of paint attach to all surfaces and tolerate each other and that a line which will soon not be needed anymore of course requires a different approach than a line which will be needed in the foreseeable future.

#### Practical aspects

The aim of coating steel towers is to prevent corrosion. Corrosion leads to a need for more expensive maintenance (such as sand-blasting and exchange of steel parts) as well as to the violation of the structural integrity of the tower and hence to the risk of its collapse [5]. Thus, coating towers is done to minimize cost and to reduce risk. The optimal moment to paint the towers would be just before corrosion starts to occur. In this way, the frequency of painting is minimized (leading to the lowest cost), but no additional maintenance (leading to surplus cost that is probably higher than the gain achieved by the reduction of the painting frequency) is necessary. Further, because corrosion is prevented, the risk of a collapse is continuously kept at the “regular” (low) level, as the tower’s structural integrity is not affected.

In practice, however, it is not possible to paint each tower at the optimal instant of time, because:

- Due to economies of scale, the price of painting decreases the more towers are treated at the same time.
- The condition of towers in one connection may significantly differ due to local circumstances (such as the presence of (salt) water or industry along the line)

Therefore, in practice the decision whether to paint or not and if so, which treatment to apply, is based on the condition of a larger group of towers or may be even on a complete line.

#### PROBABILISTIC PLANNING

#### Planning of condition based maintenance

Condition based maintenance principally complicates planning and budgeting of maintenance, as the instant and the cost of maintenance are unsure by nature. The reason for this is that the development of the condition of the installation over time is not known in advance (since if this were the case, a simpler time based maintenance approach could be applied). When the number of installations falling in one budget is (very) large, this is not really a problem, because the maintenance data can be analyzed and average intervals and
costs can be determined. Together with a list of the times having passed since the installations were maintained, the average interval and cost allow a quite accurate estimate of the future cost profile over time although the evolution of the condition of individual installations is not known.

As a matter of fact, many network operators may not have so many overhead lines that they can budget the conservation of steel towers in this way; particularly not because always larger numbers of towers or even complete lines are treated at once for reasons mentioned above. Because nevertheless a long term overview may be useful, a probabilistic approach towards overhead support maintenance planning has been developed.

This approach is considered particularly useful if historical inspection results are scarce. When elaborate records of inspection results are available, trend analysis for individual lines may give a more accurate picture of the future maintenance requirements, particularly for the next few years. As a matter of fact, the additional information can also be incorporated in the method, by changing the probability distributions depicted in figure 4 according to the inspection results.

Modeling approach

The core of the model for investigating the future maintenance cost profile of an inventory of towers is a probability distribution of the chance that a certain treatment suffices to get a tower’s coating “as new”. The distinguished treatments are:

- No maintenance
- Spot-painting
- One layer of paint
- Two layers of paint
- Two layers of paint with additional treatment (sandblasting, steel part exchange)
- Complete renewal of the tower

In figure 4, the distribution of the probability that a certain treatment suffices years is depicted over a period of 50 years. Note that the sum of the probabilities in each year equals one, as always one of the treatment types must be applied. Note as well, that this probability distribution is just a (realistic) example, but that other probability distributions can be used without affecting the principle of the method.

Using the probability distribution in figure 4 and assumptions for the cost of each treatment, the future maintenance cost profile for any inventory of (groups of) towers of which the year of the last treatment is known, can be calculated. If no budget limit is indicated, each tower is spot-painted as soon as this is necessary. The maintenance frequency is quite high, but the cost per treatment is relatively low. With a budget limit of 0 Euro, no towers are treated until they are in such a state that two layers of paint and additional treatment are necessary, the budget limit is overruled. Thus, maintenance frequency is lower, but cost is much higher.

As can be seen in figure 5, without a budget limit, all towers are spot-painted as soon as this is necessary. The maintenance frequency is quite high, but the cost per treatment is relatively low. With a budget limit of 0 Euro, no towers are treated until they are in such a state that two layers of paint and additional treatment are required, which leads to overruling the budget limit. Thus, maintenance frequency is lower, but cost is much higher.

The same exercise is carried out for a more realistic line inventory. A total of about 100 lines is taken, of which the period since the last treatment varies between 1 and 18 years and the number of towers between 10 and 60. Again, the model is run for 50 years with and without a budget limit. The results are depicted in figure 6.
As can be concluded from figure 6, it is generally cheaper to give towers a light treatment as soon as necessary, rather than postponing maintenance until more elaborate treatments are required. An additional advantage of this is, as mentioned above, maximum reduction of the risk of impairment of the tower’s structural integrity. It can also be concluded that this may require a substantial initial investment to treat the “older” towers quickly, which is however more than offset by future savings.

CONCLUSIONS

In the paper, the condition based maintenance of tower coatings was discussed. First, it was concluded that tower coating maintenance is an obvious candidate for a condition based maintenance regime, as the inspection cost is relatively low when compared to both superfluous maintenance and failure, and because the condition of tower coating can be determined quite accurately.