SUMMARY

The paper describes the causes of conductor joint defects, long and short time current carrying capacity and discusses how to select the most probable locations for failures.

Proactive methods for improving the reliability, i.e. selection of components and assembling techniques and the need for rehabilitating methods are discussed. The paper also highlights various inspection techniques to enable the condition and available operational performance to be assessed.

In case of reduced electrical capacity, failure may occur if the design limit load exceeds the residual capacity. The paper describes how to determine the action level.

The paper also describes the possibility of estimating the residual lifetime and the growth trend of failure frequency based on data from inspections. The asset manager will then be able to establish or improve a basic inspection strategy and maintenance programme.

1. INTRODUCTION

There is an increasing tendency among Norwegian utilities to try to extend the lifetime of existing overhead lines instead of replacing them. This must be worked out when the networks are still satisfying the requirements of safety and continuity of power supply.

With the increasing economical pressure to utilize the existing line capacity it is important to know the current carrying capacity of the existing electrical joints to avoid increasing failure rates.

In order to maintain failure rates at acceptable levels and at reasonable costs, efficient inspections have to be performed to locate any defects before failures are generated.

2. CONDUCTOR JOINT DEFECTS

The consequence of deterioration is that the joint becomes warm which further increases the rate of oxidation. Over a period of time, the joint resistance will increase resulting in excess current flow in the steel core of the conductor.
3. CHARACTERISTICAL CAUSES OF DEFECTS AND TIME-DEPENDENT DETERIORATION

The possible probability or consequences of a defect or failure can be estimated by a closer fault analysis of the joint problem. The reliability of the electrical joints for overhead lines, OHL, is defined as their probability to perform a required function under a set of conditions for a specified period of time achieved by appropriate design. It is thus a measure of success in accomplishing its required function. The reliability of electrical joints is dependent on external and/or internal causes. The failure of a defective joint can be accelerated by a more adverse external cause (Figure 3.1).

3.1 Design and structure of connectors for overhead lines

A connector is defined as a device for connecting a conductor to an equipment terminal or for connecting two or more conductors to each other. For the purpose of overhead lines, through connectors are used for connecting two consecutive lengths of conductor and branch connectors are used for connecting a branch conductor to a main conductor. Most midspan joints used on bare electrical overhead conductors have been of the compression type and wedge type clamps. Bolted joints are used in jumpers and as branch connectors.

An internal failure cause of connectors can be an initial defect due to fault in design.

3.2 Load and environmental influence

Failure occurs if the overload exceeds the design strength. An external cause is generally unforeseen and sudden, and the moment of failure could not be foreseen by prior inspection or monitoring. Examples are short circuit stress, increased current load, alternating current load, and icing. The failure of a defective joint can be accelerated by a more adverse external cause.

To operate overhead lines more effectively, it is vital to know the current carrying capacity of the joints. The consequence of extreme permanent current load combined with increased joint resistance is that the joint becomes warm and the conductor close to the joint overheated. The duration of temporary increased currents may be shortened when high resistance joints exist (Figure 3.2.1).
3.3 Properties of electrical joints

In case of reduced strength or conductivity failure occurs if the design limit load exceeds the residual mechanical or electrical capacity. An internal cause is most often a gradual defect in use. Overheating of the joints arises from inadequate compression along the length of the joint, mainly due to either poor design or installation problems. This will allow moisture penetration and results in oxidation of the internal aluminium surfaces between the joint and conductor. The resistive aluminium oxide reduces the paths for current flow and may cause micro arcing within the joint. Moreover, the resistance of the joint may increase due to the reduction of the contact force (material relaxation), as a consequence of ice formation inside the joint, thermo-mechanical stresses, different thermal expansion of involved materials, conductor vibrations, etc.

<table>
<thead>
<tr>
<th>Mechanisms</th>
<th>Causes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tangential</td>
<td>During a contact force reduction the material deformation may cause separation of the contact points. It is therefore important to maintain the force by means of elastic elements (i.e. cup springs).</td>
</tr>
<tr>
<td>Longitudinal</td>
<td>For through connections and jumper joints, longitudinal forces may result in tangential movements when the contact surfaces are insufficiently roughened during the installation.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Mechanisms</th>
<th>Causes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plastic deformation</td>
<td>Different materials with different thermal linear expansion (mechanical connectors)</td>
</tr>
<tr>
<td>Creep</td>
<td>Low internal elasticity, soft conductor, high compressive stress, high temperature.</td>
</tr>
<tr>
<td>Flattening of conductor</td>
<td>Connectors designed for a wide cross-section range have normally spacious conductor grooves to fit the maximum conductor size.</td>
</tr>
<tr>
<td>Cracking or fracture</td>
<td>Skewed assembly of connector body and/or conductor. Repeatedly loading and unloading of force in the area of yielding causes material brittleness. Too high assembling force (bolt torque).</td>
</tr>
<tr>
<td>Frost forces</td>
<td>Connector sleeve in a loop, ungreased conductor or unsatisfactory draining caused by a plug of grease or a watertight wall inside vertical or inclined installed sleeves.</td>
</tr>
</tbody>
</table>
Mechanisms | Causes
--- | ---
Low assembling force | No torque wrench used, wrong assembling force (both torque not specified), poor or wrong bolting, dimensional discrepancy between conductor and sleeves.

Uneven force distribution | Contact design giving uneven force distribution, too small and thin washers.

Bad | No preparation of contact surfaces with abrasives, the design of the contact causes insignificant oxide breaking of the contact surface.

Good | Insufficient oxide-breaking contact surfaces

Unsufficient sealing of the contact surfaces | Lack of contact grease in contact surfaces, oxidizing contact grease, no grease between conductor strands, unsufficient covering, connector installed at the bottom of a loop and unsufficient draining of a connector sleeve.

Too small contact area | Short connectors, contact sleeves with few and unsufficient indents, covered parts of conductor with insulating tape etc, contact grease containing solid particles in mechanical connectors, bent conductors and unsymmetrical installation of conductors in sleeves.

**Infra Red (IR) Thermography**

A malfunction of a joint, which is caused by increased contact resistance, may be detected by means of Infra Red Thermography when the increase of resistance results in a temperature rise of the joint surface.

To obtain a reasonable assessment of the actual condition of the joint, it is advisable to take into consideration background conditions, current load dependent heating, and changes in emissivity. It is recommended that the survey is carried out during load periods with 50-70% of the thermal load limit, low wind speeds, no rain or snow and no sun. The use of Infra Red Thermography is very practical and the instruments can be used either from the ground or from a helicopter.

**Joint Resistance Measurer**

Various devices are available which can be used on live line or on disconnected and dead circuits. Measurements carried out by this method are more complicated compared to Infra Red Thermography, but the advantage is that it gives an earlier and more precise indication of the joint condition (Figure 4.1).

**K-value Measuring**

The k-value is the ratio of the resistance of a connector to that of the resistance of the equivalent length of the conductor [3]. The value has no dimension and can be used directly to gauge deterioration. In principal the method is not subject to current loading, temperature, weather conditions and emissivity.

**Visual inspection**

Visual inspections can be carried out from a helicopter, from the ground or by support. To obtain a good and objective assessment it is essential that the linesman has good experience.
5. ACTION LEVEL

In case of reduced current carrying capacity, failure may occur if the design limit load exceeds the residual capacity. Based on collection of some old exposed joints of identical design and type, the action level (critical k-value) can be defined by carrying out current load experiments on joints with unequal k-value. The goal is to find the current carrying capacity of a defined design and structure of connectors for overhead lines.

The results of current load experiments of three compression jumper joints with different k-values are shown in Figure 5.1. Calculated thermal limit load by 20 °C is 1582 Amps and the joint with k-value = 2.3 exceeds this limit. The critical k-value of a joint is defined as a condition with stable energy balance without temperature gradients along the conductor (Figure 5.2). It is possible to determine the current carrying capacity of an old connector arrangement if the thermal limit load of the conductor is known, and the critical k-value and the current carrying capacity of joints with unequal k-value is known (Figure 5.3).

6. RESIDUAL LIFETIME

The possibility of estimating the residual lifetime and the growth trend of failure frequency based on data collection from inspections, will make the asset manager able to establish or improve a basic inspection strategy and maintenance programme.

A lifetime model for joints has been established. This model is based upon:
- Original k-value. The reference gauge ought to be carried out one year after installation.
- Age
- k-value measured at the moment
- Action level (critical k-value)

The model is calibrated against gained results from life tests of a number of joints at field stations. By means of the lifetime model the change of state for 12 random jumper joints can be followed (Figure 6.2).

Based upon the estimated k-values (Figure 6.2) and the electrical capacity of joints with increased resistance (Figure 5.3), it is possible to calculate the present and expected electrical capacity in the future.
In principal it is now possible to estimate how the distribution function \( F(x) \) for current capacity will change in the course of time. The probability in exceeding the electrical capacity (maximum conductor temperature 80°C, 0.6 m/s wind speed, overcast) is described in Figure 6.3.

Figure 6.3 The growth trend of probability in exceeding the electrical capacity of a connector arrangement can be estimated for a given current load.

In order to obtain a maximum accuracy of the function \( F(x) \) for current capacity, it is required to carry out a sufficient number of sampling tests. The uncertainty can be described by means of the confidence interval where the width of the interval decreases when the number of samples increases.

Regarding inspection strategy and maintenance programme the reliability \( P(X>x) = R(x) = 1-F(x) \) can be calculated by means of a so called Kaplan–Meier estimator and plotted into a diagram that indicates the probability of survival for a certain period of time for the jumper joints of overhead transmission lines (Figure 6.4).

Figure 6.4 The Kaplan–Meier plot diagram indicates the probability of survival for the jumper joints of two overhead transmission lines (OHL 1 and 2) exposed to different environments.

8. CONCLUSIONS

Concerning inspection of and assessment of electrical joints for overhead lines it is suggested to:

- Define a goal
- Define requirements
- Make a review of relevant types of failure causes
- Make a clarification of critical problems
- Clarify the need for different kind of resources
- Define the action level
- Choose between suitable inspection techniques
- Establish or improve a basic inspection strategy and maintenance programme.

REFERENCES


[3] Compression and mechanical connectors for power cables with copper or aluminium conductors, CEI IEC 61238-1, 1993-08.