Thermography of Aged Contacts of High Voltage Equipment

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SUMMARY

New developments in diagnostic tools and systems are necessary for a reliable and economic evaluation of the condition of equipment in power systems. In a research project a tool for the condition of contacts of centre break disconnector, which is used under normal operation by the aid of a thermography measurement system, has been developed.

In this paper, an overview about the laboratory investigation of the temperature load behaviour and the environmental influence on-site for new and aged disconnector contacts are given. A condition evaluation tool for contacts, which was the aim of the project, was created. The basic method for the evaluation is presented and also two additional easements for a fast identification of suspect contacts are presented.

With this evaluation tool and the usage of a thermography based measuring system, a condition based maintenance strategy can be applied, whereby an early detection of damages is possible and so the power quality and reliability increase.

KEYWORDS

High Voltage Disconnector, Contact Diagnostic, Thermography, Aged Contact
1 Introduction

During the last 15 years the transmission situation and the electrical stress in the European power grid has changed totally. During the unbundling of the power producers from the transmission grid, the economic interests diverge. In addition, the operators of the grid have to maximize their profits and so they are interested to lower the expenses for maintenance. On the other hand the consumers claim an increasing reliability of the energy supply and power quality. Also nowadays entitlements to damages are not rareness. So the operators of transmission systems have to increase the reliability of their components to minimize the economic risk of an unexpected outage [7].

The reliability and the quality of a high voltage grid are based on the condition of every single component of the transmission path. Each single device is coupled with an electrical contact to the next one of the current path; so, many contacts are used in a grid. They are stressed by the permanent changing load flow and a huge number of external impacts.

Additionally the servicing strategy has changed from a time or event oriented maintenance to a condition based maintenance strategy [8].

In a research project in cooperation with an Austrian grid operator investigations of disconnector contacts were done. The aim of this project was to evaluate aged disconnector contacts during the normal operation by using an infrared temperature measurement (thermography). With the results of the condition evaluation further arrangements for inspection, maintenance and operation can be made.

2 Contact Behaviour

A contact is the electrical connection of two conducting elements. Contacts are generally dimensioned to withstand all arising demands without failure. During the usage, environment and operation influences lead to a contact aging (Fig. 1). The application of contacts with high reliability and long life span can reduce such failures.

The operators are interested to be able to recognize possible faults in time with a condition evaluation. The contact resistance describes the contact condition. If a homogeneous conductor is separated into two parts and will be build up again, the resistance is increasing. This increase can be related to the constriction and tarnish layer resistance (Fig. 2). The inherent resistance is determined by the used materials. Every technical surface has a roughness and so the contacting area is smaller than the theoretical area and evokes the constriction resistance [1-3].

By chemical reaction or mechanical partial damages, foreign substances form a tarnish or corrosion layer in the contact area. In most cases these layers are semiconductive and cause an additional resistance, the so called tarnish layer resistance.

The three partial resistances (inherent, constriction and tarnish layer resistance) change by aging, whereas the tarnishing layer has the largest aging effect on the contact resistance.

2.1 Contact Condition

By the aging of the contact area, the contact resistance will increase during the operation time. For the resistance measurement different methods are practicable. Low resistances measuring bridges (Thomson or Kelvin) can be simply realized with direct current supply [4].
For a meaningful investigation of the current behaviour of contacts, the contacts must be loaded with rated currents (continuous rated current, maximum asymmetric short-circuit current). The nominal currents of contacts are in the kA range in the electrical power applications. The DC generation is possible but a high expenditure is necessary. In comparison to DC-sources, AC-sources are substantially simpler and more economical. A shorted turn at a transformer can be used as a simple solution. The disadvantage is that the time-varying AC-current causes an additional voltage drop at the contact inductance. This influence can be minimized by a suitable choice of the connection points and completely eliminated by a real power measurement of the contact point but requires a considerable expenditure for the instrumentation.

The electrical measurements are depending directly on the contact resistance. The absorbed real power in the contact area is converted into thermal power and leads to a rise in temperature of the contact parts. This temperature change can be used as derived value for the contact condition evaluation. For the measurement of surface temperatures different methods can be used. A contactless temperature measurement system, such as thermography, can be used under high voltage operation. [5][6]

2.2 Temperature Behaviour

At a (contact) resistor, a current produce thermal power according to Ohm’s law. At balanced condition, the converted electrical and thermal power is equal to the heat dissipation by thermal conduction of the conductor and the surrounding insulation material, heat radiation and natural or forced convection. The individual parameters are temperature-sensitive and a more complex interrelationship occurs.

\[
P_{\text{dissipate}} = P_{\text{load}}
\]

\[
f(P_{\text{conduction}} + P_{\text{radiation}} + P_{\text{convection}}) = f(I^2 \cdot R_{\text{contact}})
\]

\[
f(I^2 \cdot R_{\text{contact}} (\text{setup, temperature}) + f(P_{\text{conduction}} (\text{setup, temperature}) + f(P_{\text{convection}} (\text{setup, temperature})) =
\]

\[
(f,I^2 \cdot R_{\text{contact}} , f\text{setup, temperature})
\]

This dependency can be solved by the aid of simulation, but the individual parameters of each component are difficult to evaluate and depend on the construction of the contact [10][11].

3 Laboratory Investigations

The aim of the research project was the creation of a practical tool for the on-site contact condition evaluation with a minimised technical effort. The basic idea for the evaluation was the measurement of the contact surface temperature. In the standards, a maximum surface temperature for the used silver plated contacts of 105°C is allowed. Manufacturer will design their disconnector and contacts so that they will not exceed this limit. With aging, the nominal heating will increase and is affected by the degree of aging and also the load current and the environmental conditions.

In the laboratory the temperature behaviour of different contacts (new and aged) at variable load and defined environmental condition has been evaluated. With the knowledge of the contact behaviour, several tests have been done on-site for improvement. The laboratory investigations were split into three parts (Fig. 3). In investigation A, the temperature load behaviour of aged and new contacts was evaluated at room temperature and calm condition. In investigation B and C, the effects of the ambient condition like different air temperature and cooling by wind were registered.

<table>
<thead>
<tr>
<th>Temperature – Load Behaviour</th>
<th>Investigation</th>
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<tbody>
<tr>
<td>Constant Environment Condition (room temperature, calm)</td>
<td>A</td>
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<tr>
<td>Ambient effects</td>
<td>(0{\text{°}}\text{C, calm})</td>
</tr>
<tr>
<td>Wind speed ((20{\text{°}}\text{C, 0÷2.6m/s}})</td>
<td>C</td>
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</tbody>
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Fig. 3: Investigation schema

3.1 Test Setup

A specially designed test setup was developed in the laboratories of the Institute for High Voltage Engineering and System Management of the Graz University of Technology for the temperature load behaviour. The test specimens were centre break disconnector with a nominal voltage of 230kV with nominal currents from 1000A up to 2500A. The contact wiper arms were used for the high current investigation without the base insulators and the drive. The test current was generated by transformers,
whereby a short turn, consisting of the disconnector contact wiper arms and an ACSR conductor, pose as secondary winding (Fig. 4).

In this setup test currents up to 3000A can be generated. The contacts surface temperatures were measured with an infrared camera. For avoiding of magnetic interference, an additional lens to gain distance from the high current conductors to the thermography system was used. Blinds were arranged for avoiding of interfering reflections of the surrounding (Fig. 5). The backside of the disconnector was measured via an optical mirror (Fig. 6).

New disconnector contacts have a shining silver-platted surface. The emission coefficient, which is necessary for the measurement, is quite low and this circumstance makes an accurate evaluation of the temperature difficultly. A heat resistant coating with an emission coefficient of approximately 0.95 provides an adequate measuring result. For aged contacts, the adherent pollution layer has already a high emission coefficient.

3.2 Measurement Results

For the evaluation of the temperature load behaviour, the disconnector was loaded with a step current and the surface temperatures of the contacts were recorded. The load current was varied from 8% to 200% of the nominal current. For the elimination of the surrounding temperature effect, the heating temperature was calculated from surface temperature and surrounding temperature.

In Fig. 7a, the temperature pattern of a new disconnector at 80% of the nominal current is shown. The steady-state temperature of each contact is about 45°C. In comparison of an aged disconnector (Fig. 7b) a higher and unequal temperature patterns occur (hot spot). The steady-state temperature of the hottest contact (KD) at 40% of the nominal current is more than 80°C. In Fig. 7c and Fig. 7d the calculated heating is shown and presents the homogeneous behaviour of new and non aged contact as well as the inhomogeneous behaviour of aged contact.
Fig. 7a: Temperature pattern of a new disconnector at 80% of nominal load

Fig. 7b: Temperature pattern of an aged disconnector at 40% of nominal load

Fig. 7c: Heating of a new disconnector at 80% of nominal load

Fig. 7d: Heating of an aged disconnector at 40% of nominal load

KA, KB, KC, KD surface temperature of contact finger according to Fig. 6
AVG................ambient temperature of the surrounding air

The highest steady-state temperature of the contacts at the specified load is used for a mathematical description (equ. 2) of the thermo electrical behaviour of aged and new contacts. In Fig. 8 the results of the measurements are shown.

\[ \vartheta(i) = \vartheta_{\text{nominal}} \cdot i^\alpha \]  
(Eqv. 2)

\( \vartheta(i) \)...........steady-state heating at load current i in K
\( \vartheta_{\text{nominal}} \).........steady-state heating at nominal current K
i.........................load current in p.u.
\( \alpha \).....................power coefficient

Depending on the condition and type of the disconnector, the power coefficient varies between 1.5 and 1.9 and is lower than the theoretical value of two. With this relationship, the steady-state heating at different load currents can be calculated, also the steady-state heating at nominal current from a measurement at different loads. The steady-state heating at nominal current is a load independent factor which represents the condition of the contact [9].

This behaviour is valid for calm environmental condition at room temperature. In investigation B and C, the environmental effects on the heating were evaluated. Due to the non stable behaviour of aged contacts, which is typical for artificial layers in the contact area, investigations on new contacts at higher load were accomplished.

Different environmental temperatures have an effect on the heating due to the different physical properties of the surrounding air. The investigations show that the effect can be neglected by comparing to the accuracy of measurement.
The main effect of the environmental condition is the cooling effect of wind and must be considered. The cooling effect can be described by the ratio of steady-state heating with and without wind.

Combined with the other mathematical relationships, the behaviour of the contact temperature is given. The condition of the contact is given by the steady-state temperature at nominal current without interfering environmental condition and can be determined from a single measurement of contact and ambient air temperature, wind speed and load current.

4 On-site Contact Condition Evaluation

For the in site contact condition evaluation, the load current is forced by the load flow and limited by the connected equipment. In most cases the maximum obtainable load currents are less or much less than the nominal current of the disconnector and also calm conditions are depending on the geographical situation of the switching station. Due to these two circumstances the temperature difference between contact and ambient air is low and the calculation error will grow. Good measurement results can be received at high load and low wind speed.

In a switching station sometimes several hundred disconnector contacts are installed and their condition must be evaluated. A reliable and easy to operate method for identification of damaged or aged contacts is necessary for an economic condition based maintenance.

4.1 Method 1

This method uses the coherence between electrical load, ambient and contact condition. With the contact temperature, the ambient air temperature, the wind speed and the load current measurement, the steady-state heating at nominal load is calculated with acquired interrelations and this represents
the contact condition. Is this value over a threshold, maintenance action should be done; otherwise the contact is as good as new.

![Diagram of contact condition evaluation](image1)

This method gives information about the contact condition and eliminates the interfering ambient and load effect. At the other hand, for each contact this condition evaluation operation must be done. It has an extensive afford and costs a lot of time.

### 4.2 Method 2

A more affordable possibility is that only suspect contacts are verified with the method 1. Therefore a reliable system is necessary to identify a possible damaged contact. Method 2 compares the three disconnector temperatures of a bay among each other.

![Example of bay disconnector](image2)

Is there a significant difference between the three phases, like Phase L1 to Phase L2 and L3 in Fig. 12, a suspect conspicuity exists and a detailed evaluation according to method 1 is adviceable. This method gives only indices about the condition and is affected by wind and load but it is a simple method for detection.

### 4.3 Method 3

A single thermal image of a disconnector contact gives specific information about the contact condition. A defect or aged contact will show one or more hot spots and the temperature distribution is different to a new contact. The appearance of hot spots or thermal inhomogeneous is used as an indicator for a detailed evaluation according to method 1.

![Example of a suspect contact](image3)

The appearance of a hot spot is independent from wind or load. But at low wind speed and high load condition the recognising of a damaged contact is easier.
5 Conclusion

During the last 15 years the situation for the transmission grid operators changed totally. Economic aspects get much more dominance and new servicing strategies, like condition based maintenance, are be applied. Therefore new powerful diagnostic systems are needed and one of these tools is the thermography. With this, a visualisation of the temperature distribution of surfaces is possible in addition to the contactless temperature measurement.

In a research project the temperature behaviour of disconnector contacts was investigated. The aim of this project was to evaluate the contact condition during the normal operation by the use of a thermography camera for realisation of a condition based maintenance strategy. The investigations show, that the steady-state heating at nominal current is a parameter, which describes the contact condition. An evaluation from one single measurement is possible by the knowledge of the temperature load behaviour and the influence of the environment on the disconnector contact.

A practicable method (method 1) for the condition evaluation was developed for on-site usage. Additional methods for an efficient detection of possible damaged or aged contact were developed. With method 2 and 3 the environmental condition and individual load current is evaluated on demand for suspect contacts and not for all contacts. So an easy and quick evaluation of the contact condition is possible.

Which this evaluation tool and the usage of a thermography based measuring system, a condition based maintenance strategy can be applied, whereby an early detection of possible damages, the power quality and reliability increases.

BIBLIOGRAPHY


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