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Real-time Monitoring of Leakage Current on Insulating Cross-arms in Relation to Local Weather Conditions

C. Zachariades, S. M. Rowland, I. Cotton,
School of Electrical and Electronic Engineering
The University of Manchester
Manchester, M13 9PL,
United Kingdom
christos.zachariades@manchester.ac.uk

Abstract - Two insulating cross-arms have been installed within a trial site near the coast of Northeast Scotland, energised at 231 kV. The trial aims to observe the electrical behaviour of the cross-arm by monitoring in real time the leakage current of the insulating members. The weather monitoring equipment installed at the site records wind speed and direction, precipitation, atmospheric pressure, temperature, relative humidity, visibility and solar irradiance. The instrumentation is complemented by cameras that provide visual verification regarding the conditions at the site. The results from the trial during June 2012 show that the cross-arm performs according to design expectations. The leakage current profile of the novel compression insulators is similar to that of the industry standard tension insulators. A relative humidity threshold of 90% has been identified which if exceeded, results in increased leakage current activity. Additionally it has been found that the prevailing wind affects the south facing cross-arm more than the west facing one. Also, the effects of precipitation have been found to be more prominent on the tension members.

Cross-arm; composite; insulator; transmission line, NCI, test facility, leakage current, monitoring system.

I. INTRODUCTION

To meet the continuously increasing electricity demand, which is pushing many transmission corridors closer to their limits, the power sector is seeking solutions for improving the power transfer capabilities of existing infrastructure. To address this issue an insulating cross-arm has been developed (Fig. 1) that can be retrofitted on existing towers enabling the uprating of lines to higher voltages. The technology is not only more economical but also negates the environmental impact associated with erecting a new line and minimises potential planning issues. It can contribute to the reduction of electromagnetic radiation at ground level and make towers less obtrusive [1].

The insulating cross-arm consists of four members, two of which are standard tension composite insulators. Utilising a combination of innovative design, and proven materials and manufacturing methods, the main feature of the cross-arm is its compressive elements. Their distinctive cross-sectional shape

makes them lighter than cylindrical alternatives while providing high compressive strength as well as resistance to bending and buckling. While mechanically their performance has been proven both in laboratory tests and during a two year trial installation [2], the departure from traditional designs coupled with limited service experience requires verification of the electrical performance of the novel insulators and the reliability of the cross-arm in general.

To alleviate any concerns and prepare for deployment of the cross-arm on the network, a live test site was commissioned in north-east Scotland in May 2012. The main aims of the trial are:

- To observe the electrical behaviour of the cross-arm and how it changes in relation to the environmental conditions.
- To compare the performance of the novel compression insulators with that of the 'traditional' tension insulators.
- To identify aspects of the cross-arm that can be improved further (insulator profile, grading devices).

Figure 1. The Insulating Cross-arm

Figure 2. Trial site location

In this paper, the trial site and the instrumentation are described in brief. Furthermore, the first results from the trial are presented. Specifically, two short periods of leakage current activity from June 2012 are examined in detail. The discussion that follows explains the observations and links the leakage current patterns with the local weather conditions, site-specific factors and differences between the insulating members.

II. THE TRIAL SITE

The substation in which the trial is taking place is situated 3.6 km from the coast. In the East, there is also a large industrial complex (Fig. 2). The site provides an onerous environment for long-term measurements.

Two insulating cross-arms have been installed on a bespoke lattice tower. One cross-arm is facing south while the other is facing west. An 8 m span of conductor connects their conductor attachment points. A 50 kVA transformer provides 231 kV phase-to-ground which is the equivalent of 400 kV phase-to-phase that the cross-arms will experience in service (Fig. 3).

III. INSTRUMENTATION

The primary cause of polymeric insulator failure nowadays is surface degradation which is affected by the local environmental conditions [3]. The hydrophobic properties of the material may diminish over time allowing the formation of continuous water paths when the insulator becomes wet [4].

Figure 3. Live trial site

Eventually, increased leakage current flow and arcing activity could lead to flashover [5].

As one of the few parameters that can practically be measured, leakage current has been associated with insulator ageing, performance and reliability [6]. For the purposes of this trial, the insulators that comprise the cross-arm are isolated from the tower using insulating brackets to enable the measurement of leakage current from the individual members. Furthermore, a weather transmitter, a 'present weather' detector (fog sensor) and a pyranometer record the following weather parameters:

- wind speed
- wind direction
- precipitation
- atmospheric pressure
- temperature
- relative humidity
- visibility
- solar irradiance

To complement the monitoring instruments, four cameras overlook the cross-arms in order to capture pollution accumulation, possible changes in hydrophobicity as well as snow and ice accretion patterns. All of the recordings are synchronised and time-stamped. Fig. 4 shows a block diagram of the instrumentation system. More details regarding the monitoring equipment and the protection system employed at the site can be found in [7].

Figure 4. Trial site instrumentation system

Figure 5. Leakage current - 5th to 7th of June 2012

IV. RESULTS

The subsequent sections describe two periods of typical leakage current activity during June 2012. The leakage current waveforms from the individual members are labelled based on the direction the cross-arm is facing, the type of insulator and the proximity to the conductor as follows:

- SC:** South Compression
- ST:** South Tension
- STc:** South Tension near conductor
- SCc:** South Compression near conductor
- WC:** West Compression
- WT:** West Tension
- WTc:** West Tension near conductor
- WCc:** West Compression near conductor

Additionally the abbreviations below are used:

- RH:** Relative Humidity
- RI:** Rainfall Intensity (average)
- V:** Visibility
- T:** Temperature

A. 5th to 7th of June 2012

Fig. 5 shows the leakage current activity on the two cross-arms during a two day period starting at 18:00 on the 5th of June and ending at 18:00 on the 7th of June. The days preceding

this period were dry, with humidity ranging between 45 % and 80 %, and easterly wind which persists for the entire period. The currents recorded in this period are steady. They have different absolute values because the individual insulator elements are all in a different geometric position relative to the conductor and each other. The compression elements also have a wider body than the tension elements.

At approximately 03:00 on the 5th, the humidity level exceeds 90% which causes the leakage current on all insulators to rise above their base value. The increase is higher on the tension members. At 12:00 on the 6th, a spell of rainfall reduces the leakage current magnitude especially on the tension insulators. A brief period of fog starting at 02:00 on the 7th, indicated by the low visibility registered on the fog sensor, contributes to the prolongation of the higher leakage current activity. By 06:00 on the 7th, the fog subsides while the temperature starts to rise resulting on the drying of the

Figure 6. WCc at 07:00 (left) and 12:00 (right) on the 7th June 2012

Figure 7. Leakage current – 21st to 26th of June 2012

insulators and the reduction of leakage current. This is corroborated by the camera images. Fig. 6 shows the WCc member at 07:00 with moisture in the form of water droplets still on its surface which by 12:00 has completely evaporated.

B. 21st to 26th of June 2012

Fig. 7 shows a period of leakage current activity spanning several days towards the end of June 2012. The wind before the 21st was blowing from the east, i.e. from the coast, turning to north-east from the 22nd onwards. The temperature at the site for the most part of this period was between 10 °C and 13 °C.

During this five day period similar patterns start to appear as for the period described earlier. On several occasions, the leakage current activity intensifies as soon as the relative humidity exceeds 90 % despite the absence of other weather effects. After the humidity drops lower than 90%, the leakage current returns to its base value.

Furthermore, intense precipitation (up to 20 mm/h) starting on the afternoon of the 22nd has a twofold effect. On one side, it causes the leakage current on the tension members to rise considerably. On the other hand, it reduces the leakage current activity for all the compression insulators. Milder intermittent rainfall at 10:00 and 12:00 of the 24th causes the leakage current to oscillate, reducing initially and rising afterwards due to the high humidity level.

At 00:00 on the 25th a combination of high humidity and the temperature dropping below 10 °C which lasts until the morning hours, results in condensation which in turn increases

the leakage current on all insulators but especially on the ST member.

V. DISCUSSION

By looking at the leakage current patterns and weather conditions recorded during June 2012, the following observations can be made:

- 1) The base leakage current for all insulators has remained the same, indicating that no significant ageing has taken place.
- 2) The insulators closest to the conductor show higher base leakage current than the rest due to capacitive coupling between the conductor, the cross-arm members and the tower.
- 3) The leakage current on the south facing insulators is consistently higher than their west facing counterparts because the predominant wind (from the east) is perpendicular to their longitudinal axis. A bigger area exposed to the prevailing weather accelerates pollution accumulation.
- 4) There is a humidity threshold of approximately 90%, which if exceeded, triggers leakage current activity on all insulators regardless of other weather conditions.
- 5) The compression members exhibit slightly higher base leakage current than the tension members directly above them. This can be attributed to their larger circumference.

- 6) The tension members exhibit higher variations of leakage current than the compression members directly below them.
- 7) All insulators show self-cleaning properties. Their leakage current reduces even after minor periods of precipitation despite the fact that the leakage current on some of the tension insulators increases briefly when a prolonged dry period is followed by rainfall.

VI. CONCLUSIONS

The first results from the live trial show that the insulating cross-arm performs according to design expectations. The leakage current patterns observed on the novel compression insulators are very similar to the ones observed on the industry standard tension insulators. Although the base leakage current profile of the compression members is marginally higher because of their bigger cross-section, their response to changes in the weather conditions is milder, with smaller fluctuations.

Further work is being undertaken in order to decouple the capacitive coupling effects and isolate the purely resistive component of the leakage current. This will ultimately normalise the leakage current values for all insulators regardless of their proximity to the conductor.

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