A COASTAL INSULATOR POLLUTION TEST STATION FOR THE EVALUATION OF THE RELATIVE AGEING PERFORMANCE OF POWER LINE INSULATORS UNDER AC AND DC VOLTAGE

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Abstract: This research is part of an ongoing programme of the investigation of the ageing performance of power line insulators. Previous work focused on the comparison of the ageing performance of different insulator materials, using the inclined plane and tracking wheel tests under AC and DC (both polarities) voltage. In this project a test station has been built at the site of the Koeberg Insulation Test Station (KIPTS) to allow testing at voltages up to 20 kV (rms AC and average DC) of insulators consisting of various materials and having different creepage lengths. The primary objective of this research is the evaluation of the ageing of power line insulators subjected to a severe marine pollution environment. The research will be conducted over a one year period, allowing coverage of all seasons of the year. This paper presents details of the design of the test station, outlines the procedures briefly and presents some preliminary results.

1 INTRODUCTION

High Voltage Direct Current (HVDC) presents a unique advantage with regard to bulk power transfer over long distances in the sense that it permits a higher power transfer density for a given right-of-way [1]. This, together with the absence of the reactive power and stability problems related to interconnected HVAC systems makes HVDC transmission very attractive.

Polymer insulators have, during the past decades, been accepted as a cost-effective option on AC power lines and are finding increased application on HVDC lines. Whereas a considerable amount of research data is available on the ageing performance of polymer insulators on HVAC lines, it is not the case for HVDC. On HVAC lines Silicone Rubber (SR) is favoured over Ethylene Propylene Diene Monomer (EPDM) for severe marine environments [2]. However, in recent studies using the inclined plane tester [3-5] and the rotating wheel test [6] it has been found that some formulations of EPDM outperform SR materials under HVDC stresses.

In continuation of the inclined plane and tracking wheel research, the present work involves insulator testing under natural pollution conditions at a site of known pollution severity. Koeberg Insulator Pollution Test Station, situated on the west coast of South Africa was selected as the site to perform these tests. This paper describes the conversion of the existing 22 kV AC test rig, also to allow for HVDC testing. Preliminary results are also presented on the effect of different creepage lengths of HTV silicone rubber insulators when energised with AC and DC voltage of both polarities. A further aspect of this project, not being reperted here, involves the comparison of different insulator materials.

2 DESCRIPTION OF TEST RIG

The Mobile test rig, shown in Figure 1, was installed at Koeberg Insulator Pollution test station is intended for the evaluation of power line insulators under severe coastal pollution conditions..

Figure 1: AC / DC insulator test rig

The original test rig was designed to test at 22 kV r.m.s. AC [2], but has now been augmented to also include testing under DC excitation. The complete test arrangement consists of a support structure with three radial arms to support a total of 30 insulator specimens. Each one of the three support arms is supplied from a different voltage source namely Alternating Current (AC), Positive polarity Direct Current (DC+) as well as Negative polarity Direct Current (DC-).

2.1 Circuit arrangement

Figure 2 shows a schematic layout of the test installation.

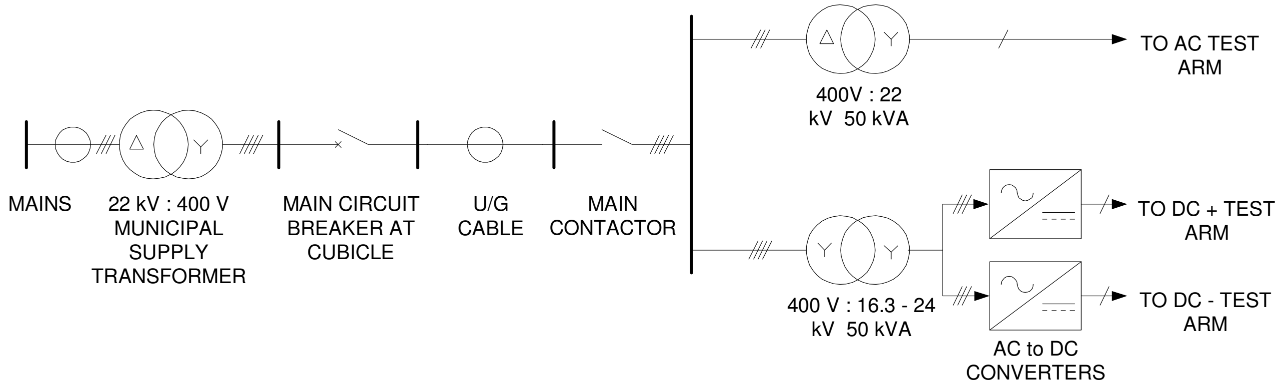

Figure 2: Schematic layout of the test installation

The AC arm of the test rig is energised from a separate 50 kVA 22kV Delta-Star test transformer. This transformer is the test transformer used for the test rig when first commissioned [2]. Only one of the secondary phase terminals is connected to one of the overhead arms with its star point connected to ground.

2.2 HVDC test arms

2.2.1 Overview

It was decided to use two separate converter units fed from a single transformer each utilising a three phase three pulse rectifier and smoothing capacitor. This smoothing technique was preferred to an inductive filter due to the transient nature of the test insulator leakage currents.

Rectifiers capable of handling the rated r.m.s current of 2 A and a reverse voltage of up to 40 kV were designed, constructed and thoroughly tested at the University of Stellenbosch. These units showed adequate performance over a three month test period.

2.2.2 Output voltage control

Since it was desired to evaluate similar Insulators under HVAC as well as HVDC excitation, a suitable output voltage for the HVDC converters had to be established. During the design phase it was thought to be used at a DC voltage corresponding to the peak value of the AC wave (22 kV system) i.e. 18 kV. However, during inclined plane testing it was decided to use DC voltage equal to the r.m.s. value of the AC voltage. The rationale was that the ageing phenomena are power driven. An off-line tap changer switch facilitates voltage adjustments.

2.2.3 HVDC Converter specifications

Table 1 shows the specifications for the 20 kV HVDC converter units.

Table 1*:* Converter specifications

Manufacturer	University of Stellenbosch
Rectifier type	3 pulse with star point grounded
Smoothing	Capacitor bank, Ripple factor 3% at 2 A
Input voltage	16.3 – 24 kV Three phase AC
Output voltage	13.3 – 19.6 kV DC
Primary phase current	1.2 – 1.8 A
Secondary maximum continuous current	2 A
Peak stored charge at 19.6 kV	3.3 kJ
Insulating / cooling medium	Main tank air. Diodes and capacitors Mineral Oil

3 TEST PROGRAMME

3.1 Test site

The test rig was installed at Koeberg Insulator Test Station (KIPTS), located along the west coast near Cape Town, approximately 50 m from the sea. KIPTS is a marine natural ageing insulator test station characterised by hot dry summers, cold wet winters, mist banks, strong winds and heavy marine pollution. The pollution index has been recorded as “very heavy” and for that reason tests at this location may be considered an accelerated test facility [1].

3.2 Choice of test voltage

The voltage sources (AC & DC) were tapped from a common supply transformer to ensure that all samples were subjected to the same electrical stress. The AC source has a 22 kV (rms) line-to-line output, with an rms equivalent of 12.7kV. As explained above, the DC sources were therefore designed to have a line-to-neutral average output of 12.7 kV.

3.3 Test insulators

The test insulators considered in this study are given in Table 2. Also shown in the table is the specific creepage length, calculated by dividing the creepage length of the insulator by the actual voltage that can appear across the insulator (r.m.s. voltage for AC and average voltage for DC, allowing for a 10% overvoltage).

Table 2: Long rod HTV Silicone Test insulators on each arm

Insulator creepage length (mm)	Specific creepage length (mm/kV)
1175	84
1010	72
780	56
615	44
400	29

3.4 Leakage current monitoring

The combined effect of the pollution that accumulates on the insulator and the high humidity that often prevails at KIPTS, causes leakage current to flow across the insulator surfaces. These currents are monitored, using an Online Leakage Current Analyzer (OLCA). Each OLCA has 9 current inputs, a three-phase voltage input and 4 weather inputs. It measures the following parameters continuously: positive and negative leakage current peaks, positive and negative leakage current averages, positive and negative charge of leakage current, rms of leakage current, insulator power loss. The leakage current parameters are derived from the measured values sampled at a 2 kHz sampling rate and the highest value is logged every 10 minutes [2]. The waveforms of the daily peak currents and the voltage are captured and stored.

3.5 Insulator monitoring

Visual inspections are done once a week on the same day the DDG and ESDD measurements are taken to minimize the down times of the test rig. The visual inspections entail the following: High Definition (HD) video recording of the insulator from two different directions; documenting any significant change on insulator surface, e.g. pollution, salt crystals, colour changes, material erosion and any other material degradation; taking pictures of observed significant changes on insulator surface.

Hydrophobicity classification of the insulator surface is done at the same time as the visual inspection. A fine mist vapour of distilled water is sprayed onto the insulator surface on the first, middle and last sheath, shed top and shed bottom from two viewpoints, landside and seaside. The hydrophobicity classifications are done according to STRI guide 1(No.92/1) and the hydrophobic state of the insulator is scored between 1 and 7 [2]. A score of 1 is given when there are single round droplets on the surface of the insulator and a 7 is given when there is a continuous water film on the surface of the insulator [2].

UV activity observations were done every night for the first four weeks. All insulators were scanned and recorded for a one minute period with the Corocam Mark I, which is an image intensified ultraviolet sensitive video camera system and with a Sony zero-lux video recorder, respectively. All the observed activities, video file names and time of the respective recordings are documented.

3.6 Monitoring the environment

The existing weather station at KIPTS measures climatic parameters such as precipitation, ambient temperature, relative humidity, UV-B solar radiation, wind speed and direction for the duration of the research period. The effect of precipitation is to wet the pollution layer on the surface of the insulator, giving rise to surface leakage currents. Too much precipitation, however, may cause washing of the insulators, thereby removing active pollution from the insulator surface. A high level of relative humidity (i.e. exceeding 75%) wets the pollution layer on the insulator surface, resulting in the flow of leakage currents. Ambient temperature affects the wetting process, especially in the early morning hours when the insulator is at a lower temperature than the ambient air. Wind affects the pollution levels by transporting and depositing pollution and moisture on the insulator surfaces [2]. Solar radiation plays a role in heating the ambient air mass and insulator surfaces and contributes directly to the ageing of non-ceramic insulator surfaces [2]. The climatic parameters were measured or calculated from the measured values sampled at 1 Hz and stored every 10 minutes [2].

The severity of site pollution is monitored using a directional dust gauge (DDG) and by measuring the equivalent salt deposit density (ESDD) and non-soluble deposit density (NSDD) on a weekly basis. The use of Directional Dust Gauges (DDG) provides a simple method to classify a site according to the amount of conductive pollution. DDGs consist of four vertical collection tubes with open slots on the sides, facing to the four cardinal directions of a compass.

4 PRELIMINARY TEST RESULTS

The results for the first four weeks (starting 3 February 2011) have indicated the electrical performance of the test insulators of the test programme. With the pollution build-up on the test insulators, the insulators began to exhibit leakage currents from the second week resulting from the interaction of pollution deposits with the wetting conditions (i.e. high humilities above 75% and ambient and dew point temperatures). No material deteriorations were observed. The test programme is still underway and the firm conclusions on performance trends for the test insulators will only be established once the first six months have been completed.

It is expected that the magnitude of the 10-minute average leakage currents depends on factors such as creepage length, type of material, surface pollution and humidity. For a specific insulator the leakage current would therefore vary with humidity and therefore vary from hour to hour. This trend can be seen in Figures 3 and 4 wherein typical time of day average leakage currents are shown for a two month period. To obtain this plot the average is calculated over the 2-month period of the 10-minute highest leakage currents measured at a specific time (e.g. 10:00)

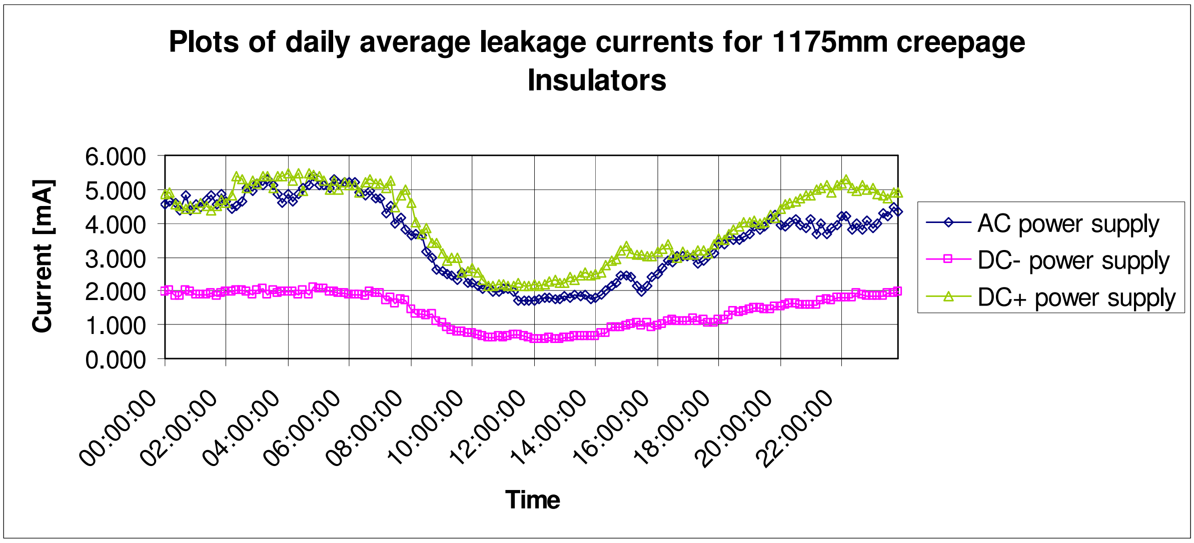

Figure 3: Time of day average of peak leakage currents for the 1175 mm creepage length HTV silicone rubber insulators for period February/ March 2011

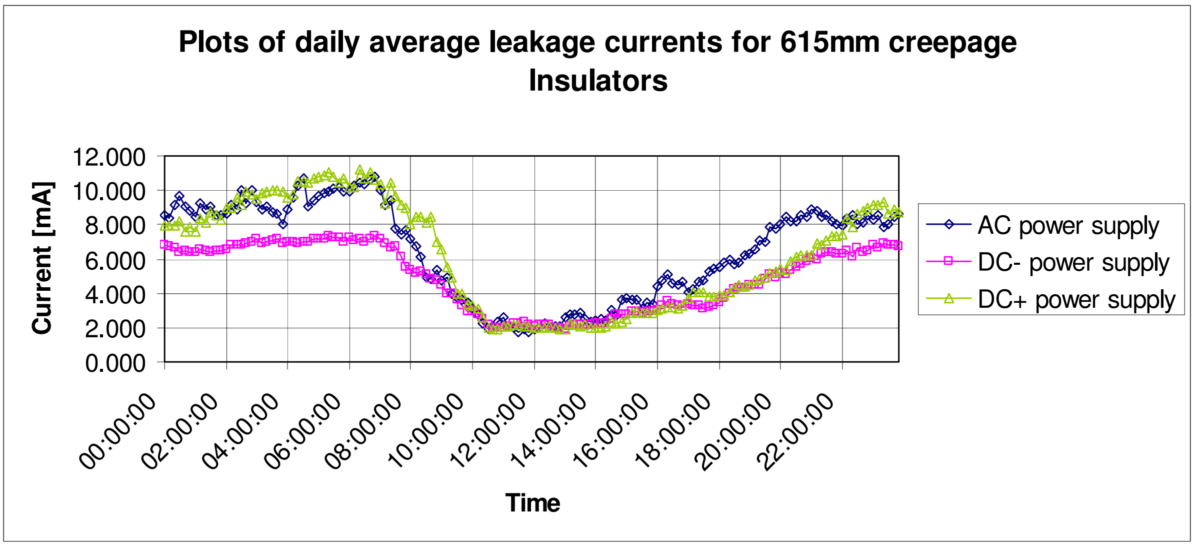

Figure 4: Time of day average of peak leakage currents for the 615 mm creepage length HTV silicone rubber insulators for period February/ March 2011

5 DISCUSSION OF RESULTS

As expected, higher leakage currents are experienced during the night, due to the higher humidity and the effect of creepage length is also visible. An interesting observation is the difference in leakage currents, depending on the type of voltage energisation. It will be noted that the AC and DC+ leakage currents are of the same order and that the DC- leakage currents are considerably lower, especially during times of high humidity. This observation is in agreement with that of Heger in inclined plane tests [4]. This effect is more evident for insulators with a high specific creepage.

The project is still in progress and the polarity effect will be further investigated. The results will also be analysed statistically, taking into account the environmental factors measured.

6 CONCLUSIONS

A high power 22 kV AC to DC converter was successfully designed, constructed and tested. The preliminary results presented in this paper have indicated the electrical performance of the test insulators for the first four weeks of the test programme. It has been demonstrated that all test insulators performed quite well during the first week. With the pollution build-up on the test insulators, the insulators began to exhibit leakage currents from the second week resulting from the interaction of pollution deposits with the wetting conditions (i.e. high humidities above 75% and ambient and dew point temperatures). No material deteriorations were observed.

The test programme is still underway and the firm conclusions on performance trends for the test insulators will only be established once the first six months have been completed. It is however envisaged that interesting results on the performance of insulators under DC voltages will be established from this research that would be helpful in aiding the design of insulators for use on DC power lines.

In another experiment that is also in progress the relative ageing performance of HTV silicone insulators and EPDM insulators is being investigated.

The research is a co-operative project involving Stellenbosch University,Eskom and NamPower, the electricity supply utility in Namibia. It is envisaged that information gathered and expertise developed during the project will assist the design of new HVDC lines in Southern Africa and worldwide.

7 ACKNOWLEDGEMENT

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