ELECTRICAL PERFORMANCE AND POLLUTION ANALYSIS OF IN-SERVICE HVDC GLASS DISCS

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Abstract: In this work, two glass insulator strings were removed from the positive pole of the Cahora Bassa HVDC line in an area where confirmed line faults have occurred during heavy mist conditions. The strings consist of 28 glass discs and have been in service for a period greater than 10 years. Tests were undertaken to evaluate the constituency and particle size distribution of the pollution deposit on the insulator strings. Further, the Equivalent Salt Deposit Density distribution was evaluated for each disc in the string in accordance with IEC 60815-1. Electrical tests were undertaken to determine the dry and wet flashover voltage of each disc of both strings for comparison to their clean rated values. The major constituents in the two samples are shown to be Zinc (Al)-oxide, quartz (SiO_2, sand), kaolinite ($Al_2Si_2O_5(OH)_4$, clay), gypsum/anhydrite ($CaSO_4.2H_2O$, “scale”) and mica (muscovite). The origin and particle size distribution of the pollutants are discussed. The Equivalent Salt Deposit Density calculation places the string in the light pollution severity class. The electrical tests confirm that there is limited degradation of the rated dry and wet flashover voltage of each disc due to the pollution deposit and continuing test work is presented.

1 INTRODUCTION

The Apollo-Cahora Bassa transmission system is at present the only High Voltage Direct Current (HVDC) transmission scheme in the Eskom network as well as the largest source of renewable power imported to South Africa. The hydro-electric scheme operates between two countries. The converter station is situated at Songo in The Republic of Mozambique, and the inverter station, at Apollo, is located near Johannesburg in the Republic of South Africa.

Hydro-electrica de Cahora-Bassa (HCB) operates and maintains the Mozambique section (approximately 900 km) while the South African section (approximately 520 km) are maintained by Eskom. The nominal system voltage is $\pm$ 533 kV. The South African section operates at up to 1592 m (mean altitude above sea level). The transmission lines consist of two 1420 km long monopoles, spaced approximately 1 km apart. The lines are insulated with both DC glass and polymeric insulators. Due to altitude variation, the glass HVDC insulator I-strings varies in length from 25 to 28 discs per string.

During the winter, low rainfall season, an increasing number of line faults are experienced. Research undertaken by Eskom has shown a correlation between humidity (> 75 %) and line fault occurrence [1]. This statistical evidence suggests that pollution accumulation as a result of limited natural washing by rain and subsequent wetting (by mist or fog) may give rise to a pollution initiated flashover event.

In this work, two insulator strings were removed from the transmission line in an area where confirmed line faults had occurred during heavy mist conditions. The strings consist of 28 glass discs and have been in service for a period greater than 10 years. The removed strings are sampled from the positive polarity line, and are shown in Figure 1 and Figure 2. The first insulator string was located in close proximity to a brick manufacturing facility and the second a few hundred meters away.

Tests were undertaken to evaluate the constituency and particle size distribution of the pollution deposit on the insulator strings. Further, the Equivalent Salt Deposit Density (ESDD) distribution was evaluated for each disc in the string removed from in accordance with IEC 60815-1 [2]. Additionally, electrical tests were undertaken to determine the dry and wet flashover voltage of each disc of both strings for comparison to their clean rated values.

Figure 1: Removed insulator strings - Tower 122.

Figure 2: Removed insulator strings - Tower 119.

The glass disc used in the string is an anti-fog DC disc. No corona rings are used on the glass insulators strings installed on the line. The discs have a creepage length 550 mm and a connecting length of 146 mm. Figure 3 is a schematic of the glass anti-fog DC disc as used on the Cahora Bassa line.

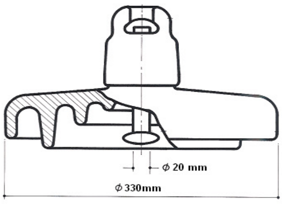

Figure 3: Schematic of the glass anti-fog DC disc as used on the Cahora Bassa line.

2 POLLUTION LEVEL ASSESSMENT

The (ESDD) distribution was evaluated for each disc in the strings in accordance with IEC 60815-1 [2]. The measured conductivity and calculated ESDD values for the top and bottom surfaces of the discs are presented for Tower 119.

2.1 Conductivity measurement and Equivalent Salt Deposit Density Results

It can be seen from Figure 4 and Figure 5 that the bottom surface has a consistently higher level of pollution accumulation than the top surface. This is expected given the electrostatic catch mechanism associated with HVDC lines [3] combined with the top surfaces being exposed to greater washing from rain and cleaning by wind.

The highest ESDD value recorded places the string in the light pollution severity class according to IEC 60815-1 [2].

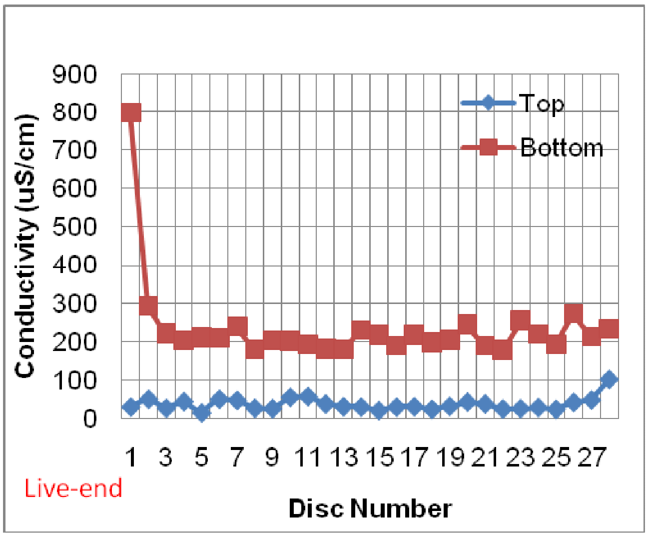

Figure 4: Measured conductivity - Tower 119.

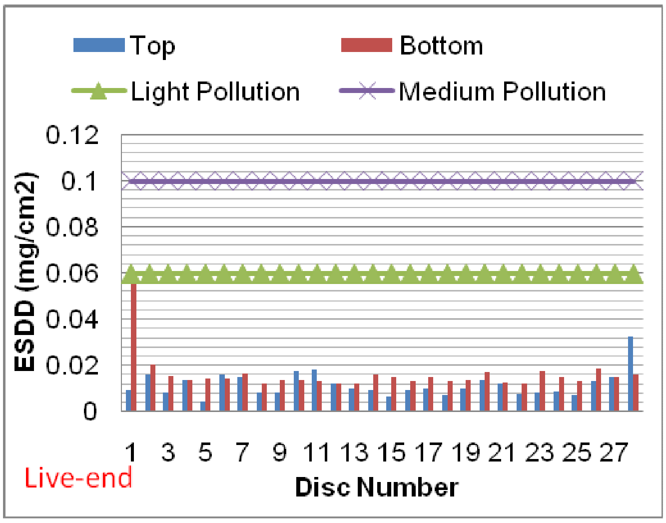

Figure 5: Calculated ESDD values - Tower 119.

3 POLLUTION CONSTITUENCY AND PARTICLE SIZE ANALYSIS

A scanning electron microscope configured to automatically determine the mineralogical composition and particle characteristics of coal, fly ash and any particulate sample using the QEMSCAN method was used to analyse samples from the two insulator strings. The results of the analysis are presented [4].

The major constituents in the two samples were identified to be Zn(Al)-oxide, quartz (SiO_2, sand), kaolinite ($Al_2Si_2O_5(OH)_4$, clay), gypsum/anhydrite ($CaSO_4.2H_2O$,“scale”) and mica (muscovite). The results of the constituency analysis are shown in Figure 6. Figure 7 illustrates the particle size distribution for Tower 119 and Tower 122.

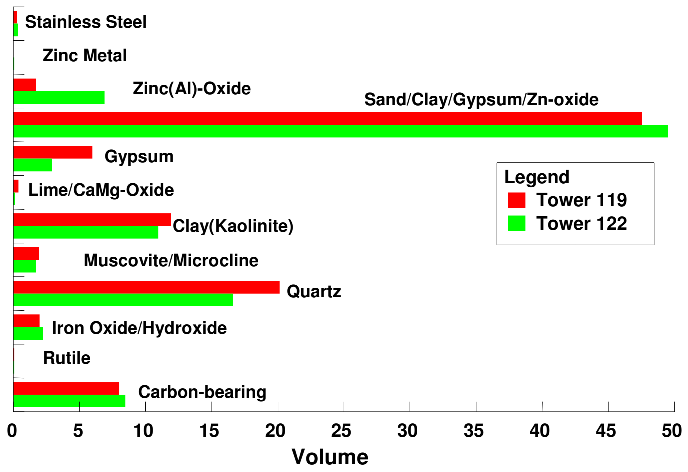

Figure 6: Predicted mineralogical proportions by percentage volume[4].

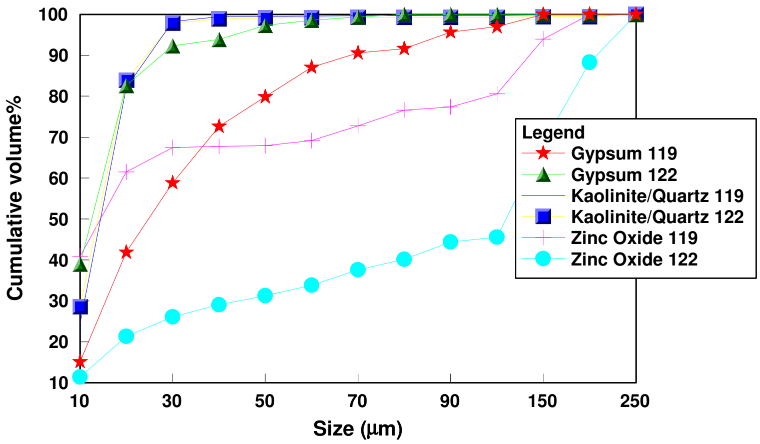

Figure 7: Combined Particle size distribution for Tower 119 and Tower 122 [4].

Between Tower 119 which was in close proximity to the brick manufacturing facility and Tower 122, a few hundred meters away, there is no discrimination between the size distribution of kaolinite/quartz. The particle size range is within that of typical air borne dust. Tower 119 yielded a higher proportion of gypsum as well as a higher proportion of coarser gypsum relative to tower 122.

The deposits on the insulators strings consisted of a fine mixture of quartz (sand), kaolinite (clay), gypsum and Zinc (Al)-oxide The gypsum will cement these fine particles into a hard deposit resistant to rain and wind. Gypsum is a by-product of lime reacting with sulphuric acid. The source of the lime is most likely to be the cement used in the production of bricks. If the brick manufacturing process is coal fired, SO_2 produced can react with moisture in the air to produce the required acid necessary for the formation of gypsum and the hard deposit seen.

The similar size distribution of kaolinite/quartz and gypsum seen on Tower 122 suggest that a higher proportion of lime/gypsum in the pollution sample of Tower 122 was wind borne. The coarser distribution of lime/gypsum in the pollution sample of Tower 119 suggests that a proportion of the sample can be directly attributed to activity within the brick manufacturing facility.

Figure 8 is a QEMSCAN false colour image of the deposits on Tower 122 [4]. The larger particle size distribution and angular nature of the zinc oxide fragments seen supports the theory that the zinc oxide fragments are the remnants of oxidation of the galvanized metal parts of the insulator disc. Sulphuric acid attack could initiate the oxidation of the galvanizing layer.

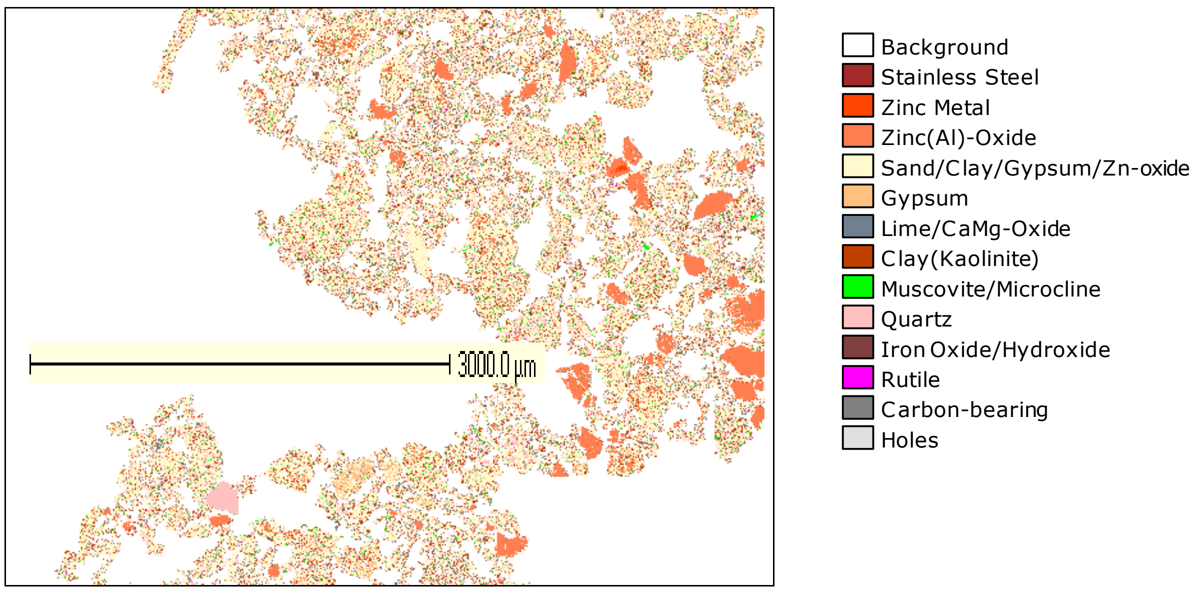

Figure 8: QEMSCAN false colour image of Tower 122 deposits. Note coarse Zinc-oxide - metal fragments.

4 ELECTRICAL PERFORMANCE

Electrical tests were undertaken to determine the dry and wet flashover voltage of each disc of both strings for comparison to their clean rated values. The rated DC, one minute, dry and wet withstand flashover values of the discs in a clean condition are ±150 kV and ±65 kV respectively

4.1 Electrical test setup

The test setup consisted of a 250 kV polarity reversible DC test set, voltage divider, current limiting resistor and associated measurement and recording equipment. The test voltage is applied to the live end of each disc and slowly increased in one minute intervals until flashover across the entire unit occurs. For the wet procedure the insulator disc is lightly wetted with de-mineralised water in a uniform manner before the test voltage is applied. A minimum of five applications of the test voltage is used to determine both the one minute withstand value as well as the test voltage at flashover for both the wet and dry scenarios.

Figure 9 and Figure 10 are recorded images from the dry and wet flashover tests.

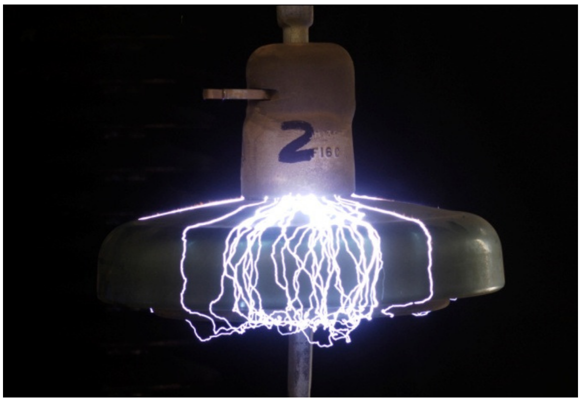

Figure 9: Recorded image of dry flashover.

Figure 10: Recorded image of wet flashover.

4.2 Flashover results

Figure 11 and Figure 12 are of the lowest obtained flashover values of the polluted discs for Tower 119 and Tower 122 respectively. The results presented are corrected to STP as per IEC 60060-1 [5].

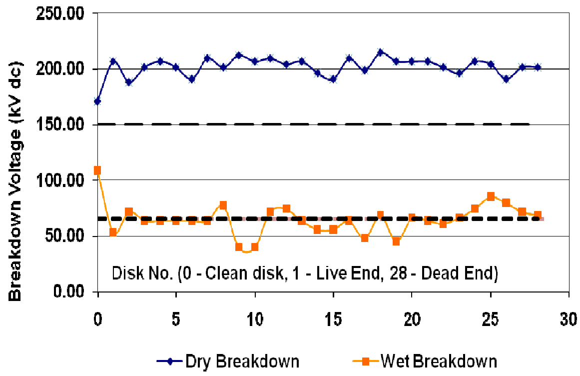

Figure 11: Lowest obtained flashover values for Tower 119.

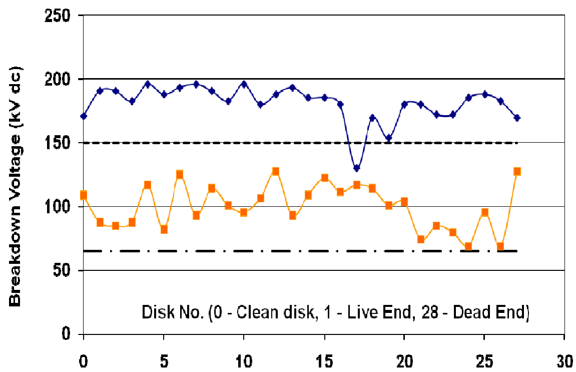

Figure 12: Lowest obtained flashover values for Tower 122.

From Figure 11 and Figure 12 it can be seen that for most cases the polluted discs perform at or better than their clean, rated values. This is expected given their light pollution severity classification.

Figure 13 is of the flashover variation with the calcuated ESDD values across the Tower 119 insulator string. There appears to be little correlation between ESDD value and flashover value for the pollution class investigated.

5 FURTHER RESEARCH

Future work is directed at obtaining a greater sample set across different pollution severity classes and comparing the effect of Non-Soluble Deposit Density (NSDD) and its influence on flashover under DC conditions together with ESDD data.

Further large scale testing is proposed to evaluate the effect of pollution on the breakdown value of a full insulator string in the presence of fog or mist under DC stress. In addition the role of space charge generated by corona needs to be quantified in these situations as there is little available data at present.

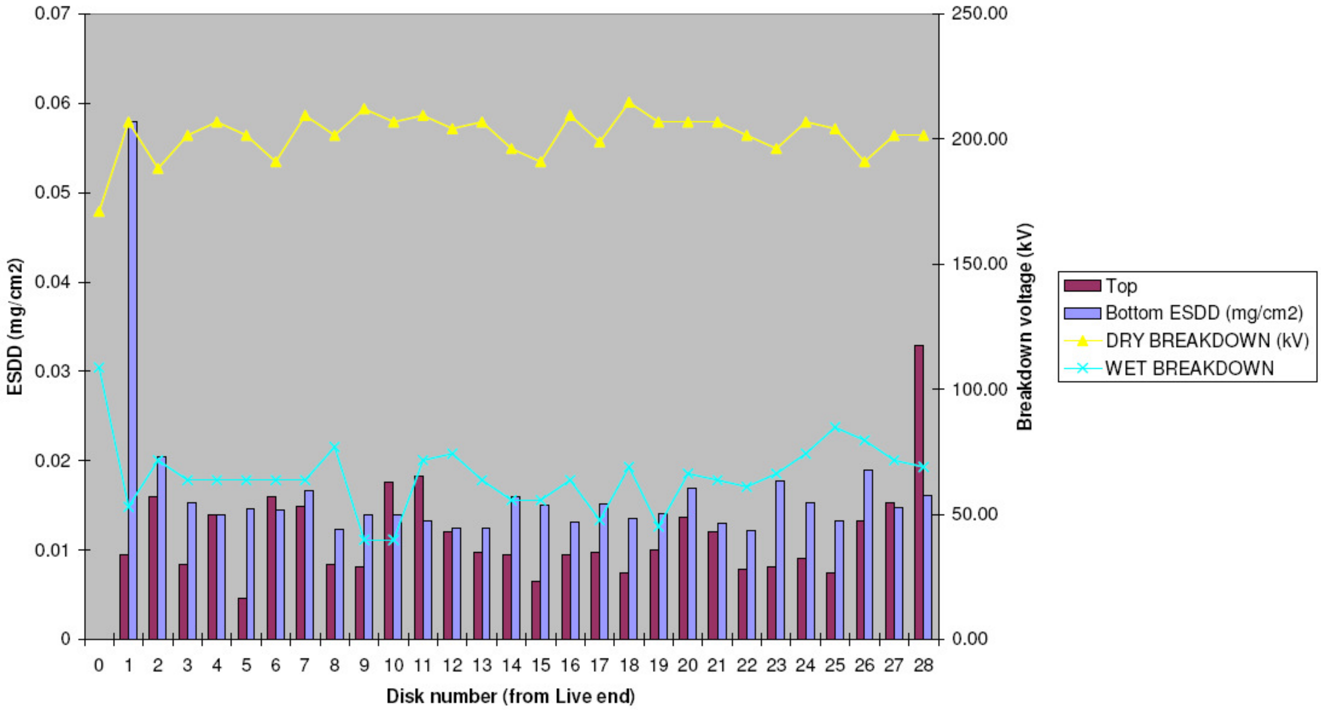

Figure 13: ESDD and flashover variation across insulator string from Tower 119.

6 CONCLUSION

The pollution analysis identified the major constituents in the two samples to be Zn(Al)-oxide, quartz (SiO_2, sand), kaolinite ($Al_2Si_2O_5(OH)_4$, clay), gypsum/anhydrite ($CaSO_4.2H_2O$, "scale") and mica (muscovite). The origin and discrepancy in particle size distribution for the gypsum seen in the two samples is attributed to activity in the brick manufacturing facility, which has also been linked to be the potential source for the oxidation of the galvanizing layer on the discs. The ESDD calculation places the string in the light pollution severity class and the electrical tests confirm that there is limited degradation of the rated dry and wet flashover voltage of each disc due to the pollution deposit.

The mechanism for complete breakdown of the insulator string has not been identified and continuing large scale test work is proposed to evaluate the influence of varying NSDD and ESDD levels in the presence of instantaneous pollution such as fog or mist in the DC breakdown process. The role of space charge also requires clarification and further evaluation.

7 ACKNOWLEDGMENTS

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8 REFERENCES

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