LONG-TERM SERVICE TESTING OF INSULATORS AT A TEST TOWER IN SOUTH AFRICA

W L Vosloo, *I Gutman, *R Hartings

SAHVEC, division of TSI and ESKOM Enterprises, Insulator Centre, PO Box 222, Brackenfell, 7561,
SOUTH AFRICA

*STRI AB, Box 707, S-771 80, Ludvika, SWEDEN

SUMMARY

This paper presents the results of 3 years of testing of 9 composite and glass line insulators, under service conditions in the Natal province of South Africa. Both pollution performance and ageing characteristics are discussed and practical recommendations for dimensioning are derived.

INTRODUCTION

A natural ageing test is the first step necessary to obtain the desired knowledge about the long-term pollution performance and ageing characteristics of composite insulators [1]. These two inputs form the basis for the verification of installation, establishment of end-of-life criteria, dimensioning rules and maintenance criteria/methods.

A coastal environment is probably the main pollution source in many highly industrialized countries and therefore of general interest to both insulator manufacturers and utilities. In South Africa, and specifically in the Natal province, the coastal environment is causing insulation problems [1].

The aim of this paper is to present the results of 3 years of testing of a specially designed matrix of 9 composite and glass line insulators mounted in a tower in a coastal subtropical region and make recommendations for the insulators selection in this environment. This paper is strongly related to a similar paper on composite insulators in a nearby but higher polluted Kelso test station to be published at ISH2001.

SITE DESCRIPTION

The Clansthal tower is located approximately 300 m from the Indian Ocean in the Natal province, where an African coastal subtropical climate prevails, i.e. average annual temperature about +24^{o}C (Max +34^{o}C and Min +8^{o}C) and average annual precipitation 1140 mm (averaged over 30 years). The tower is partially protected from the sea wind by a vegetation.

The overhead line operates at 88 (100_{max}) kV phase-to-phase voltage and the insulators at the tower have been energised since February 1997.

SELECTION OF INSULATORS

To obtain maximum information from a minimum number of test samples a special insulator matrix of 9 insulators was established (so called “selective approach”). It comprises samples of 3 different materials, 4 different manufacturers, 3 different profiles and 2 different operating positions (suspension/tension), see details in TABLE 1.

TABLE 1 DESIGN PARAMETERS OF NINE INSULATORS.

Material and code	Specific creepage [mm/kV]	Arcing distance [mm]	Suspension/ tension (# insulators)
SIR-A	29.0	890	T(2)
SIR-B	28.7	963	S(1)+T(1)
SIR-C	28.0	744	S(1)+T(1)
EPDM-C	28.0	744	S(1)+T(1)
Glass-D	30.5	1606	T(1)

MONITORED PARAMETERS

The parameters which were continuously or periodically monitored at the tower included:

- Different leakage current and weather parameters, according to [1], measured by the real-time data logger system OLCA produced by the CT Lab in South Africa;
- Visual observations and hydrophobicity measurements, according to [2] and ESDD, according to CIGRE requirements.

As reported in [3], surveys on service experience normally give an indication of the total insulator market. The CIS (Composite Insulator Status) program gives an indication of what kinds of damage occur during service and how they are related to the design of the insulator and the environment in which it operates [3]. The results of field testing presented in this paper are considered to be even more detailed than in CIS “magnification glass” for the insulators’ behaviour. The standardised, detailed, high-quality data, relevant to the dimensioning of the insulators is discussed further.

AGEING CHARACTERISTICS

Deterioration and damage

The results of a visual inspection of the insulators after different periods of service are shown in TABLE 2 and illustrated in fig 1.

TABLE 2 TYPICAL TYPES OF DETERIORATION/DAMAGES AFTER 2-3 YEARS IN SERVICE. C=Colour Changes; LE=Light Erosion; CH=Chalking; S=Splitting; CR=Corrosion.

Material and code	Type of deterioration/damage after years in service		
	2 y	2.5 y	3 y
SIR-A-T	C	C	C
SIR-B-S	C	C	No data
SIR-B-T	C	C	C
SIR-C-S	C	C, LE	No data
SIR-C-T	C	C	C, LE
EPDM-S	CH	C, LE, S	CH, LE, S, CR
EPDM-T	CH	CH	CH, LE, S
Glass-T	No	CR	CR

Within 3 years in service EPDM insulators (both suspension and tension) show a clear tendency towards deterioration (from chalking to splitting of the rubber). Silicone rubber insulators show only minor ageing phenomena.

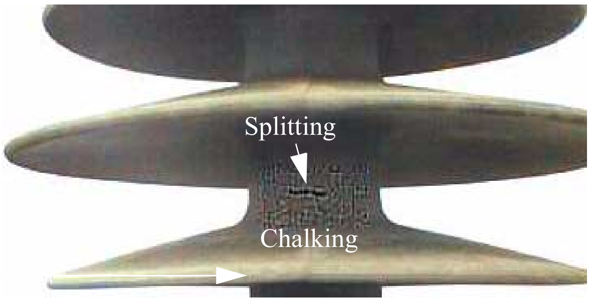

fig 1 Example of deterioration/damage: chalking and splitting of the rubber on EPDM-S insulator.

POLLUTION PERFORMANCE

Flashovers

No insulator flashovers occurred during 3.5 years of service in this coastal area.

Pollution parameters: ESDD

All ESDD measurements on U120BS glass cap-and-pin insulators for the period 1997-2000 (24 measuring points) are presented, statistically, in fig 2. For practical calculations it is considered that the ESDD values are distributed according to normal distribution. The parameters of the distribution are: $ESDD_{mean}$ = 0.056 mg/cm^2; standard deviation σ is 44%. Based on these parameters, an ESDD value for the accumulated probability 99% is calculated as 0.118 mg/cm^2. Both $ESDD_{50\%}$ and $ESDD_{99\%}$ are about two times lower than the same parameters at nearby but highly polluted Kelso station.

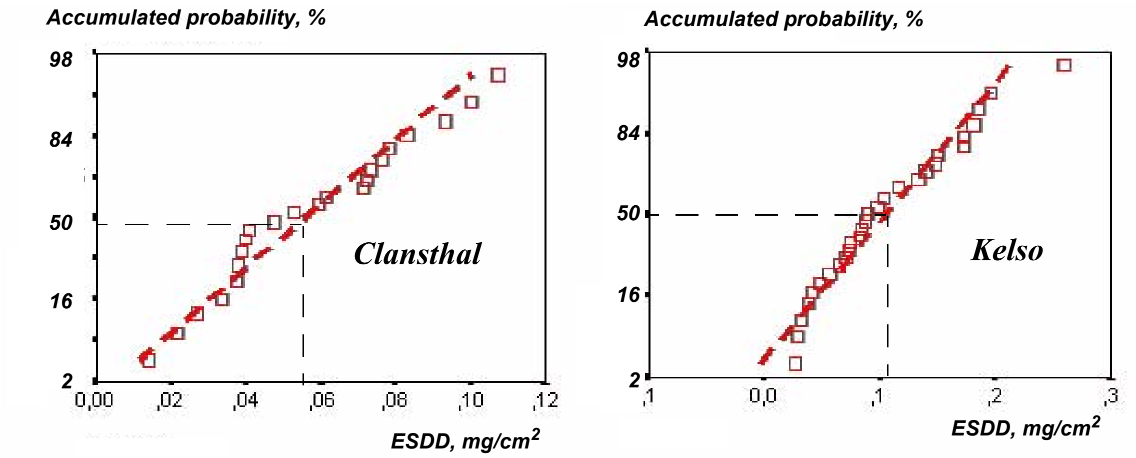

fig 2 Distribution of the ESDD measurements on U120BS glass cap-and-pin insulator in comparison with a normal distribution at Clansthal and Kelso.

Hydrophobicity vs type of insulator material

The variation in the average hydrophobicity class (HC) over service time, measured according to [2], is shown in fig 3.

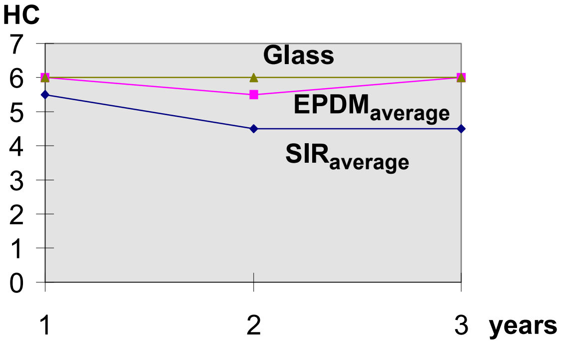

fig 3 Variation in the $HC_{average}$ over service time for different materials: 6 SIR insulators, 2 EPDM insulators and one glass insulator. HC 7: the surface is totally wetted; HC 1: the surface is totally hydrophobic (water repellent) [2].

Leakage current vs insulator material and vs position

To compare the different insulators, the leakage current for different materials and test positions of all 3 years is presented in three graphs: absolute maximum current during three years (fig 4, A); average of three annual maximum currents (fig 4, B) and average of three annual accumulated powers, i.e. UxI_{rms} (fig 4, C). The latter is considered as a parameter related to the ageing processes on the surface of an insulator.

Based on the results presented in fig 4 there is a clear difference between the silicone rubber, glass and EPDM materials. From the maximum current point of view the EPDMs always perform more poorly than all other materials, see A and B. Therefore, they should have the lower pollution performance than other materials. The poorest pollution performance among silicone rubber insulators have suspension SIR-C insulators, which perform even more poorly than tension glass insulators. Other types of silicone rubber insulators, SIR-A (tension), SIR-B (tension and suspension) and SIR-C (tension) have significantly lower maximum peak currents. The similar order of merit is obtained for the annual accumulated power, which is more “ageing” parameter of leakage current. In this case the poorest performance has glass insulator which may be explained by typically longer duration of the leakage current pulses on hydrophilic glass insulators. Based on the annual accumulated power, suspension SIR-C insulators perform even more poorly than EPDM insulators. Other types of silicone rubber insulators, SIR-A (tension), SIR-B (tension and suspension) and SIR-C (tension) have significantly lower annual accumulated power. Two different types of silicone rubber suspension insulators perform more poorly than tension insulators do. This is especially clear for SIR-C insulators. This difference is not so clear for the almost hydrophilic EPDM insulators.

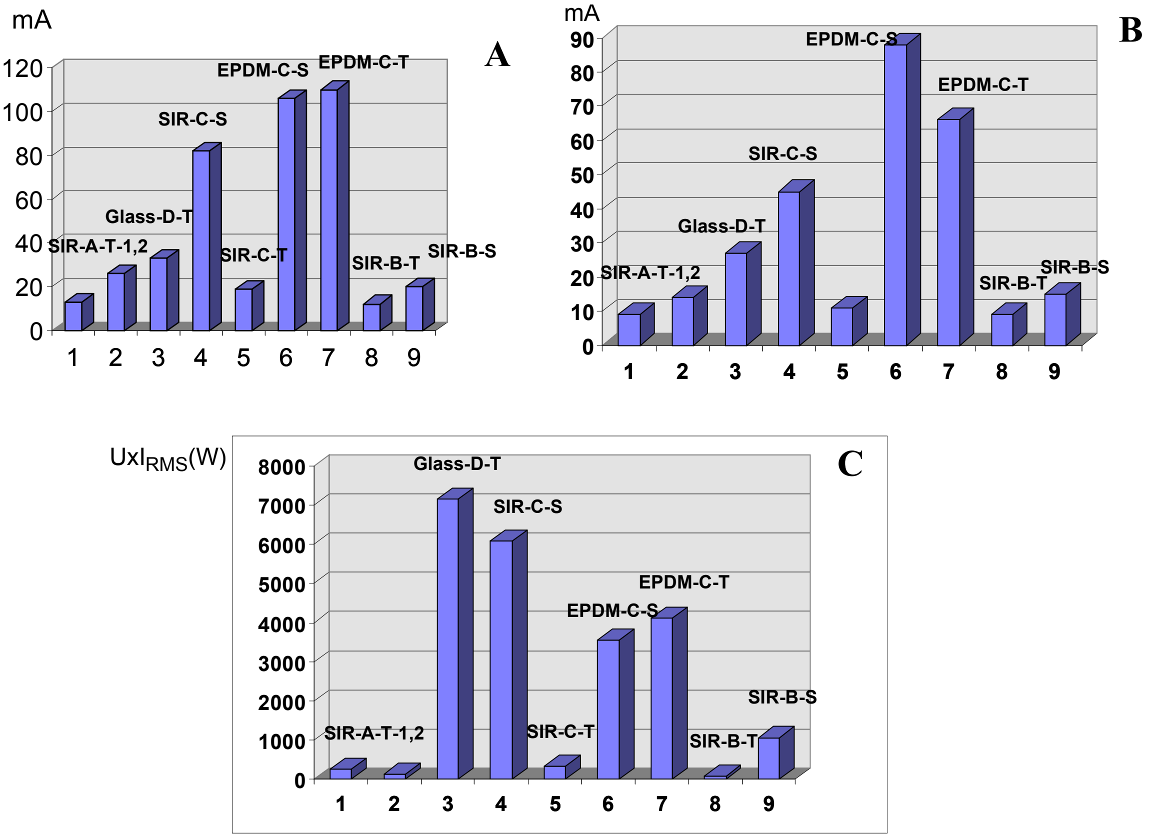

fig 4 *Histogram of the maximum peak current observed during a 3 year period (A). Histogram of the average of the three annual maximum peak currents (B). Histogram of the average of the three annual powers (UxI_{RMS}) (C).*

Leakage currents vs critical weather parameters

The pollution events related to the maximum leakage currents on EPDM insulators were investigated in detail. These events occurred on 1999-08-23 (110 mA on EPDM-C-T) and on 1999-09-16 (106 mA on EPDM-C-S). Relatively high currents were observed on all 9 insulators simultaneously. The following most important weather parameters were obtained in both cases: wind from the sea; relative humidity close to 100% (exceeding 95%); light rain, with an intensity of 0.1-0.2 mm/min.

ESTIMATION OF THE NUMBER OF OUTAGES FOR OVERHEAD LINE IN THE SAME AREA

A relatively high leakage current was observed only on EPDM insulators. These insulators are used as an example of the probabilistic estimation of the number of outages for the 100 km overhead line located in the same area, which will be rather conservative (low probability for ESDD, no truncation for the flashover voltage probability distribution).

As a starting point the ESDD$_{99\%,}$ as derived from Section is 0.118 mg/cm^2. Based on the relationship between the ESDD and surface conductivity, investigated under natural and artificial conditions in South Africa [4] and Russia, this value is considered to correspond to 18 µS. (This value corresponds well with other estimations; i.e. if the max voltage is 100 kV and the max current 100 mA then, taking into account the form factor k_F=15, the conductivity is 15x0.1/10^{-5}, i.e. 15 µS which is almost the same as 18 µS derived above from ESDD measurements).

The number of flashovers per 100 kV of line per year n can be calculated using a statistical approach widely used in Russia for overhead lines dimensioning of hydrophilic insulators [5] (which corresponds with the HC measurements for EPDM shown in fig 3):

$$n = mN \bullet F\left[\frac{1-\frac{U_{50}}{U_{ph-max}}}{\sigma\frac{U_{50}}{U_{ph-max}}}\right]$$

where:
m - number of insulators, m=1200 for 100 km of 88 kV line located in the same area; N - number of "dangerous" wettings leading to the risk of the flashover, N=max 2 per year according to the complete 3 years leakage current data presented in fig 5 (maximum two extremely high current peaks approaching the level of 100 mA); F - normal distribution; U_{50} - 50% flashover voltage of a given insulator (EPDM-C-S) for the given severity level (18 µS). $U_{ph\text{-}max}$ - maximum phase-to-ground voltage; σ - standard deviation of the flashover voltage, σ=0.1 [5].

The flashover voltage U_{50} is calculated using data from [6] i.e.:

$$U_{FO} = 2,27\left(\frac{K_F}{\chi}\right)^{\frac{n}{n+1}} L^{\frac{1}{n+1}}$$

where: K_F (form factor) = 15; χ (surface conductivity) = 18 µS; n (the parameter of partial arc) = 0.3 [6]; L (leakage distance) = 280 cm.

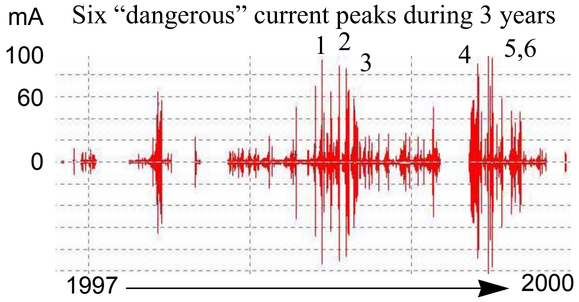

fig 5 Complete peak current data for the insulator EPDM-S during February 1997-March 2000 (3 year data).

The results of the calculations of "n" are as follows: for the overhead line equipped with the EPDM-S insulators with 29 mm/kV, the number of outages is estimated as 0.06 per 100 km per year, which is acceptable. For the same line equipped with the same insulators with 25 mm/kV the number of outages will be increased to 2 per 100 km per year, which is considered unacceptable.

DISCUSSION ON INSULATORS SELECTION

Based on the results of 3 years service experience in a subtropical coastal area partially protected from the sea winds, the following suggestions for dimensioning are obtained:

- Based on the ageing characteristics and pollution performance of EPDM line insulators from manufacturer "C", these insulators are not recommended for use in the Natal coastal area. From the pollution performance point of view, a specific creepage distance of 29 mm/kV is needed for these insulators. Material deterioration is detected within a short time, leading to a surface, that is close to hydrophilic (fig 3) and later on splitting in the sheath.

- The current on the suspension silicone rubber insulator from the same manufacturer is also the highest for all silicone rubber insulators tested. It is also not recommended to use these insulator in the natal coastal area;
- The silicone rubber insulators from manufacturers "A" and "B" can be recommended to be installed in service. Neither pollution nor ageing problems are observed for the specific creepage 29 mm/kV and therefore a specific creepage of 25 mm/kV seems to be sufficient. The hydrophobicity of silicone rubber insulators is at the level HC 4-5 (not completely hydrophilic), which is in line with other observations in the coastal area [3];
- Glass insulators with specific creepage 31 mm/kV have no major pollution problems and perform similarly to silicone rubber insulators. Corrosion of the metal flanges may be a problem in the long-term.
- All silicone rubber tension insulators perform better than suspension insulators. This may be explained, firstly, by the orientation of the tension insulators towards the sea and therefore a quite different pollution accumulation performance in comparison with suspension insulators. Secondly, the effect of wetting (by rain) will also be quite different for these two working positions. It seems that these two effects are not so pronounced for EPDM almost hydrophilic insulators.

CONCLUSIONS

The high-quality data derived from a sophisticated test tower makes it possible to select insulators for the practical service in the investigated subtropical coastal area ($ESDD_{50\%}$=0.056 mg/cm^2; $ESDD_{99\%}$=0.118 mg/cm^2) with high level of confidence: silicone rubber insulators from two manufacturers with the specific creepage distance 25 mm/kV may be recommended.

ACKNOWLEDGEMENTS

The authors acknowledge the key role of ESKOM and STRI in supporting the research on which the paper is based.

REFERENCES

[1] I. Gutman, R. Hartings, W.L. Vosloo, "Field testing of composite insulators at Natal test stations in South Africa", ISH99, London, UK, August 1999, paper 4.50.S19

[2] STRI Guide: "Composite Insulator Status Program: Field inspection of composite insulators", Guide 3, 98/1, 1998

[3] A.J. Maxwell, R. Hartings, "Evaluation of optimum composite insulator design using service experience and test station test data rom various pollution environments", CIGRE Session 2000, 33-203, 2000

[4] L. Van Wyk, W.L. Vosloo, J.P. Holtzhausen, "Relation between surface conductivity, leakage current and humidity on ceramic insulators", 31st UPEC Conference, Iraklio, Crete, September 1996

[5] N.N. Tikhodeev; S.S. Shur: Insulation of electrical network. Energy, Leningrad, Russia, 1979 (in Russian)

[6] I.Yu. Gutman, "Methodology of calculation of flashover voltages of polluted rod insulators", 7th ISH, Dresden, August 26-30, 1991, 43.18