Microbiological growth analysis on a 275 kV transmission line composite insulator in South Africa

AUTHORS:
Rembuluwani P. Tshubwana[1]
Chandima Gomes[2]
John van Coller[2]
Thierry J.C. Regnier[3]

AFFILIATIONS:
[1]Department of Electrical Engineering, Tshwane University of Technology, Pretoria, South Africa
[2]School of Electrical and Information Engineering, University of the Witwatersrand, Johannesburg, South Africa
[3]Department of Biotechnology and Food Technology, Tshwane University of Technology, Pretoria, South Africa

CORRESPONDENCE TO:
Rembuluwani Tshubwana

EMAIL:
tshubwanarp@tut.ac.za

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Transmission line silicon rubber insulators are frequently subjected to harsh environmental conditions that can change their surface characteristics and result in a transient or permanent loss of hydrophobicity. Algae, fungi, mould, and lichen are examples of biological growth that can compromise the power system's ability to operate safely by lowering the insulator's flashover voltage. We evaluated and identified the major microorganisms that could be responsible for the flashovers of insulators in South Africa. Due to the difficulty of accessing insulators currently in use within the electricity network, only two insulators, from two provinces in South Africa, were used in the study. Although algae were not found on the insulators, two major filamentous fungi identified as *Curvularia* sp. and *Aspergillus* sp. were isolated. The absence of algae could be attributed to the weather pattern of the two locations where the insulators were placed during their use as part of the network. According to previous studies worldwide, the high occurrence of these fungi could be linked to the reduction of flashover voltage of the composite insulators. Although a larger survey including more insulators from all provinces in South Africa should be conducted, the current study demonstrates the need for a cleaning programme for insulators using cost-effective eco-friendly antimicrobial agents.

Significance:

- Degradation and loss of hydrophobicity on the overhead line composite due to biological growth were found to be an impediment to the safe operation of high-voltage insulators. Fungi were found to be the main factor causing the degradation of overhead transmission lines.
- With these data, a model can be developed to predict the rate of biological growth on a given insulator, to estimate the degradation of the surface conditions with time for the utility to know when to remove them from the line. Such a model could lead to a more reliable and efficient power system and reduce the engineer's workload.

Introduction

Transmission line silicon rubber insulators can be degraded when exposed to extreme environmental conditions. This degradation could be due to biological growth. Several studies on the biological growth of microorganisms on insulators, especially on porcelain and silicon rubber insulators, have been conducted in various countries.[1] In Sri Lanka and Tanzania, insulators exposed to tropical climates (with medium to high humidity) were colonised by algae and mould, under both polluted and clean conditions. In general, microorganisms were found on 33 kV porcelain and glass insulators.[2] Algae and lichen were retrieved from porcelain insulators in areas characterised by low pollution, high rainfall, and high humidity.[3] Colonisation of insulators by green algae has been reported from Asia, Australia, and even Europe, making it the most undesirable microorganism to be targeted when a cleaning programme is implemented.[4] Under wet conditions and biological growth, the flashover voltage decreases by 25–75%. Due to the inorganic components that comprise silicone rubber insulators, which fungi and other microbes cannot digest, biological growth is significantly lower than on porcelain insulators.[4] Biological growth such as moss and algae was discovered on insulators placed in muddy wetlands in New Orleans[5], and even years after silicone rubber insulators were installed, biological growth was found in nations like Germany and China[6]. According to the reports, a wet, contaminated surface had a three times higher leakage current than a dry or clean surface. Also highlighted was the connection between biological growth, which covered one third of the insulator, and the leakage current level of 50 μA at the specified 127 kV phase-to-ground voltage. It has been reported that countries like Sweden and India, with temperate and tropical climates respectively, regularly find biological growth, including algae, fungi, and bacteria, on the surfaces of insulators.[7] Limited reports are available regarding the occurrence of microorganisms on composite insulators in South Africa. Therefore, this preliminary study focused on determining and identifying the major microorganisms present on different parts of the insulator.

Properties of composite insulators

Composite insulators are made from cross-linked polydimethylsiloxane (PDMS). These materials have several properties, such as:

- Hydrophobic surfaces
- Low surface free energy
- High surface mobility
- Good dielectric properties
- Non-adhering surfaces

- Excellent resistance to weathering
- Insolubility in water
- Low reactivity and toxicity
- Low glass transition temperature

They also have the advantage of being lightweight, which makes them uncomplicated to install. Composite insulators have excellent surface hydrophobicity. Polymeric insulators have replaced ceramic units for a wide range of reasons, including lower weight, less cost, high mechanical strength, and resistance to contamination.

Hydrophobicity of silicone rubber insulators

The hydrophobic property plays a crucial role in ensuring the safe and stable operation of silicone rubber insulators. However, the hydrophobic properties of high-voltage insulators are diminished by the presence of biological organisms such as fungi, mould, and lichen. The hydrophobicity of the silicone rubber insulator was found to be significantly compromised due to the presence of algae contamination, particularly in a humid environment. Silicone rubber materials have been seen to facilitate the provision of nutrients necessary for the growth of fungi, potentially leading to modifications in the electrical characteristics of the insulator. These phenomena typically occur in regions characterised by tropical and subtropical climates, where the temperature spans from 0 °C to 40 °C.[8]

Composition of biofilms

Microbial communities that inhabit a substrate that is resistant to biological degradation have a propensity to develop a cohesive layer on the material's surface. A biofilm consists of bacteria that are enclosed inside a matrix of extracellular polymeric substances, mostly polysaccharides and proteins, and are highly hydrated. The film frequently contains a combination of bacterial, fungal, protozoan, and algal communities.[9] Nevertheless, the proportion of viable cells within a fully developed biofilm is frequently minimal. In most biofilms, water is the prevailing ingredient in terms of abundance, while the organic component of the film is frequently characterised by a dominance of extracellular polymeric substances. Furthermore, the mature biofilm may contain particle debris, such as clay, humic compounds, and corrosion products. When attempting to identify the root cause of a biofouling issue, there is a tendency to underestimate the significance of the microbial population within the biofilm, inadvertently disregarding its role in the fouling process.[10]

Adherence and growth of biofilms

Biofilms are produced by microorganisms that exhibit the expression of genes responsible for the synthesis of surface features, such as the production of extracellular polymeric substances, as well as the regulation of growth rate.

Physicochemical considerations encompass various parameters that influence biological processes. These elements include substrate composition and roughness, temperature, pH, water potential, and oxygen supply.

Stochastic processes encompass the initial colonisation and subsequent random fluctuations in both biotic and abiotic variables. Deterministic phenomena refer to the occurrence of specific interactions between species, such as competition, cooperation, and predation. The mechanical mechanisms involved in this study include the application of shear forces resulting from the interaction of water or airflow with the substrate. The configuration of the biofilm is contingent upon the interactions between the bacteria and their immediate surroundings. Nevertheless, most biofilms have a structure like that of a sponge, characterised by the presence of interconnected pores and channels. This intricate network allows for the unrestricted movement of a liquid phase inside the biofilm, facilitating the efficient transfer of oxygen and nutrients throughout various regions of the biofilm.[11]

Materials and methods

Composite insulators

Figure 1a–d illustrates the two composite insulators that were tested and their locations. The two 275 kV composite insulators were donated by Eskom and were removed from the line because they flashed over during normal operation. As both insulators had been in operation for more than 10 years, they had been exposed to elements that would have decreased the hydrophobicity of the shed substance.

Power frequency current leakage tests

The insulators were hung on the test apparatus in the same way in which they were attached to the line. Each insulator's two electrodes were each linked to a voltage source terminal with variable power and frequency. Insulators were sprayed with water at a 45° angle so that the maximum precipitation rate under wet conditions would be 5.08 mm per minute. According to IEC 600112 specifications, the resistance of the water used for spraying was determined to be 9.45 k per cm^3 at standard ambient pressure and temperature. Rain was simulated on the insulator for 15 min. The power frequency voltage was applied and raised gradually until it reached the desired level. The humidity was 40%, the pressure was 849 kpa, and the temperature was 13 °C. Figures 2 and 3 show the outcomes for both dry and rainy conditions.

Environmental conditions of the locations

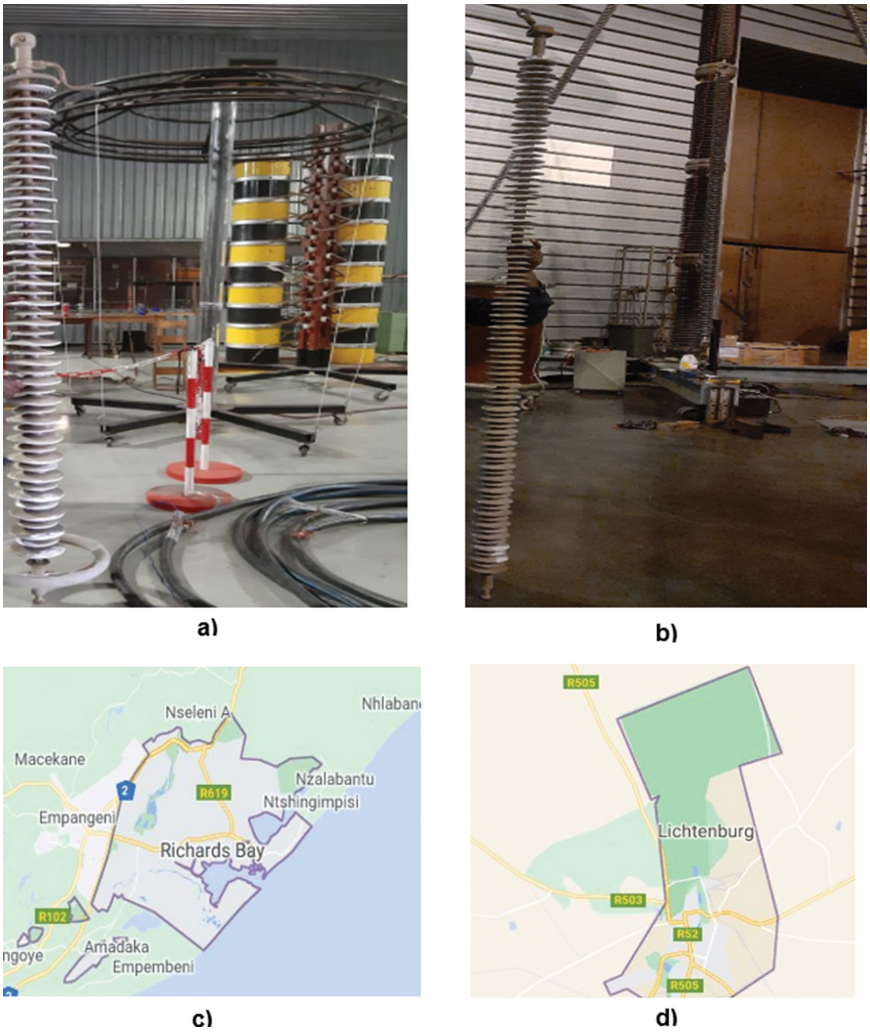
The Richard's Bay climate is tropical with summer rainfall and cold weather in winter. The annual rainfall is 1228 mm. The annual average temperature is 21.5 °C.

Lichtenberg has a semi-arid climate; the annual average temperature is 17.3 °C and approximately 609 mm of precipitation occurs every year.

The environmental conditions for insulator A and B are reported in Supplementary figures 1–8. All weather data sets were provided by the South African Weather Service.

Microbiological analysis

Swabs were used to detect the presence of microorganisms on three randomly selected discs ($n = 16$ per insulator). Both surfaces ($n = 2$ per top and $n = 2$ per bottom) of each chosen disc were sampled because exposure to rain and sunlight could affect the biodiversity of the microorganisms present. The samples were packed in a cooler box, and transported to Tshwane University of Technology (Pretoria, South Africa) where they were stored at 4 °C until further use. Each swap was aseptically placed into a test tube containing 10 mL of sterile Ringer's solution (Merck, Johannesburg, South Africa). Up to 10^6 sequential decimal dilutions were generated. With 100 μL of each dilution, the spread plate technique was used to conduct microbiological analysis. Following the incubation of inoculated Petri plates with Plates Count Agar (PCA, Biolab, Johannesburg, South Africa) for 48 h at 30 °C, the presence of total mesophilic aerobic bacterial colonies was noted. After five days of incubation at 25 °C, mould and yeast counts were performed using Dichloran Rose Bengal Chloramphenicol Agar (DRBC, Biolab, Johannesburg, South Africa). Based on the presence of the colonies, pure isolates were obtained from a single spore as described by the authors.[10] These pure isolates were placed in the culture collection and identified using the molecular technique. The partial gene sequences of translation elongation factor 1α (EF1α) were examined to genetically identify five major isolates from insulator A and eight isolates from insulator B. A ZR Fungal/Bacterial DNA MiniPrep™ extraction kit (Zymo Research) was used to extract genomic DNA from pure cultures of each fungal isolate using about 100 mg of mycelium. Gel electrophoresis was used to verify the isolation of the DNA. The primers EF1 + EF2 [5'-ATGGGTAAGGAGGACAAGAC-3' and 5'-GGAAGTACCAGTGATCATGTT-3', respectively] were purchased from Inqaba Biotec (Pretoria, South Africa) for use in polymerase chain reaction (PCR) amplification. The identity of the fungal isolates was confirmed by comparing the EF1α nucleotide sequences to fungal sequences in the genetic database.



Source (c) and (d): Google Maps

Figure 1: (a) 275 kV insulator A from KwaZulu-Natal. (b) 275 kV insulator B from Lichtenburg. (c) The geographical location of insulator A. (d) The geographical location of insulator B.

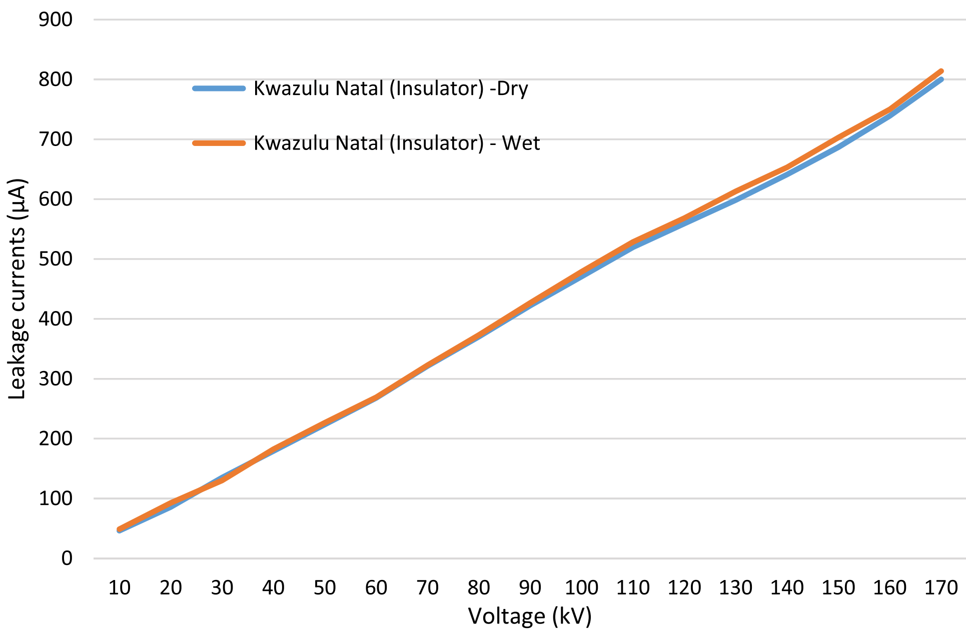


Figure 2: Insulator A's leakage current in dry and wet environments.

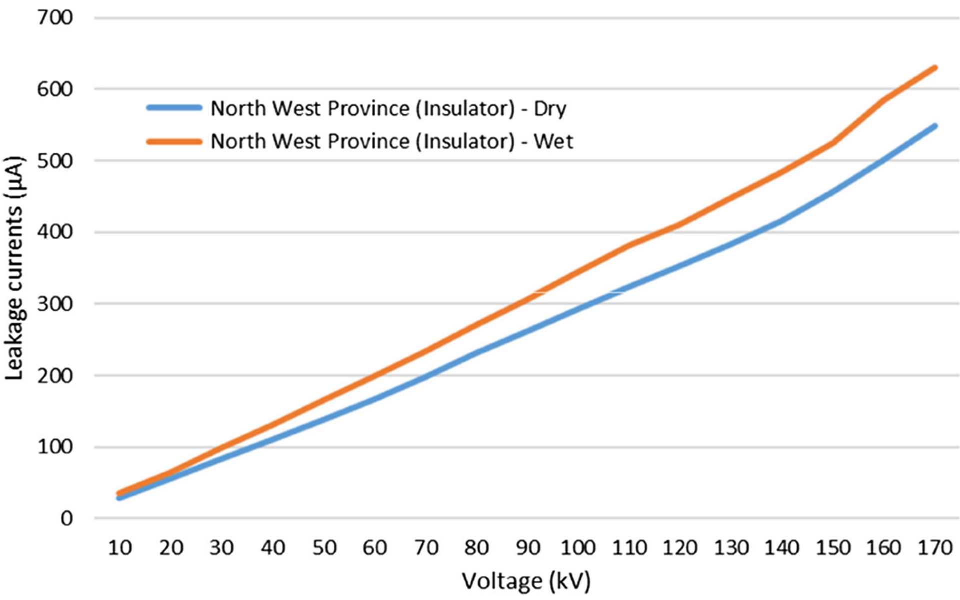


Figure 3: Insulator B's leakage current in dry and wet environments.

Results and discussion

Microbial population

As anticipated, there was no pattern in the distribution of microorganisms on the insulators within the discs, regardless of where the swabs were taken. Disc 1 did not support the development of any microorganisms (Table 1), despite its location on the top portion of the insulator and exposure to sunlight. On the other hand, more microorganisms, primarily filamentous fungi, were present on the discs in between. Surprisingly, none of the discs examined could be used to isolate yeast or algae, not even on the insulator from Richard's Bay, a coastal region on the Indian Ocean, only filamentous fungi.

The identification of the filamentous fungi was emphasised considering the discs' mould contamination. Numerous species have been documented to grow on composite insulators and the variety and quantity of the microorganisms, primarily filamentous fungi, differed amongst insulators depending on ambient factors, materials used, and shed design.[11] Although there have been earlier reports of filamentous fungi on insulators in Florida and other parts of the world, to our knowledge, no studies have been conducted in South Africa to identify the fungal populations on the insulators currently used in the country. *Curvularia* sp. and *Aspergillus* sp. were prevalent filamentous fungi that developed on the insulators (Table 2).

In a study on the potential use of laser-induced fluorescence for the detection of fungus covering insulator materials, *Curvularia* sp. and *Aspergillus* sp. were previously isolated from insulators in different countries.[11] Despite reports of green algae microorganisms on 500 kV transmission line insulators, none of the two insulators – particularly insulator A, which was based near the coast and subject to subtropical weather and high humidity – had any isolated algae. However, a larger number of insulators must be selected to verify the occurrence of filamentous fungi and the absence of algae and yeast contamination.[12] For this reason, further studies should be done using a larger number of insulators, including those from the coastal areas of the Eastern and Western Cape Provinces of South Africa. The presence of filamentous fungi, which might cause the sheds' hydrophobicity to decrease, may be the cause of the leaking currents seen on insulators A and B. This could explain why these insulators' flashing is over-recorded. Based on previous studies, natural essential oils were tested on ceramic tiles, for their ability to suppress several filamentous fungi such as *Curvularia* sp. and *Aspergillus* sp.[13] Several oils, including those from *Mentha piperita* L. and thyme oil, were recovered using exchanges.[14] Strong antibacterial action was shown by the essential oil thymol and by R- (-)-carvone to suppress this fungus. However, biocidal antimicrobial molecular barrier treatments are also recognised for their ability to reduce the growth of bacteria on surfaces in industrial settings, necessitating more research and testing of such solutions' potential for use on insulators.[15] Additionally, wiping after washing the insulator in water, wiping the dry insulator with cotton swabs dipped in salt water or tap water, or cleaning de-energised insulators can be done in a variety of ways, including through vigorous hand wiping of the dry insulators. However, further research is required to determine how to remove mould in electrified environments.

Conclusions

This article underlines the importance of investigating the presence of microorganisms on insulators. The occurrence of these microorganisms is scientifically poorly known in South Africa. The findings of this paper show that filamentous fungus colonised insulators used in South Africa over time, which led to flashover. In that sense, this preliminary research demonstrates the need for further investigation in South Africa. Although perhaps optimistic, investigation of the potential prophylactic use of essential oils and therapeutic solutions is encouraging as a cost-effective alternative for removing contaminants on the insulators and must be investigated further using more microorganisms (including fungi) isolated from a larger number of insulators.

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Competing interests

We have no competing interests to declare.

Authors' contributions

R.P.T.: Conceptualisation; methodology; investigation and formal analysis; writing – original draft preparation; writing – review and editing. C.G.: Conceptualisation; investigation and formal analysis; writing – review and editing. J.v.C.: Writing – review and editing. T.J.C.R.: Methodology; writing – review and editing.

Table 1: Presence of microorganisms on two different insulators

Sample description	Total count (CFU/mL)	Yeast and mould (CFU/mL)
Disc 1 Top - Insulator A	TFTC	TFTC
Disc 1 Top - Insulator B	Nothing	Nothing
Disc 1 Bottom - Insulator A	1190.00 ± 91.33	1113.33 ± 85.05
Disc 1 Bottom - Insulator B	Nothing	Nothing
Disc 2 Top - Insulator A	Nothing	Nothing
Disc 2 Top - Insulator B	Nothing	Nothing
Disc 2 Bottom - Insulator A	344.33 ± 35.12	138.00 ± 19.47
Disc 2 Bottom - Insulator B	Nothing	Nothing
Disc 3 Top - Insulator A	18 500.00 ± 458.26	16 266.67 ± 1305.12
Disc 3 Top - Insulator B	171 333.30 ± 19 731.53	Nothing
Disc 5 Bottom - Insulator A	TFTC	Nothing
Disc 5 Bottom - Insulator B	22 800.00 ± 793.73	22 366.67 ± 929.16
Disc 23 Top - Insulator A	Nothing	Nothing
Disc 23 Top - Insulator B	Nothing	Nothing
Disc 24 Top - Insulator A	Nothing	Nothing
Disc 24 Top - Insulator B	TFTC	Nothing
Disc 25 Top - Insulator A	Nothing	Nothing
Disc 25 Top - Insulator B	Nothing	Nothing
Disc 45 Top - Insulator A	Nothing	Nothing
Disc 45 Top - Insulator B	Nothing	Nothing
Disc 45 Bottom - Insulator A	2363.33 ± 75.72	1846.67 ± 335.01
Disc 45 Bottom - Insulator B	46.33 ± 4.16	TFTC
Disc 46 Top - Insulator A	Nothing	Nothing
Disc 46 Top - Insulator B	Nothing	Nothing
Disc 46 Bottom - Insulator A	136 333.30 ± 1154.70	22 300 ± 700
Disc 46 Bottom - Insulator B	15 066.67 ± 776.75	2446.67 ± 15.28
Disc 47 Top - Insulator A	Nothing	TFTC
Disc 47 Top - Insulator B	Nothing	TFTC
Disc 47 Bottom - Insulator A	Nothing	Nothing
Disc 47 Bottom - Insulator B	546.67 ± 80.83	540.00 ± 52.92

Values are the mean±SD of 30 plates

TFTC, too few to count; CFU, colony forming units

Table 2: Significant filamentous fungus identified from the two insulators

Insulator A	Insulator B
Curvularia trifolii	*Thielavia terricola*
Curvularia protuberata	*Sordaria tameness*
Lecythophora sp.	*Curvularia lunata*
Aspergillus fumigatus	*Trichoderma citrinoviride*
	Lecythophora sp.
	Aspergillus fumigatus
	Aspergillus niger

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