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Behavior of Rubber Materials under Exposure to High Electric Fields

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Published in:
Proceedings of the 23rd NORDIC INSULATION SYMPOSIUM

Publication date:
2013

Document Version
Publisher's PDF, also known as Version of record

Proceedings of the

23rd NORDIC INSULATION SYMPOSIUM

June 9–12, 2013
Trondheim, Norway

Department of Electric Power Engineering

NORWEGIAN UNIVERSITY OF SCIENCE AND TECHNOLOGY

ISBN 978-82-321-0274-7

Layout: The authors
Cover Layout: Akademika Publishing
Paper: Gprint 90 gr
Printed and binded by AiT Oslo AS
Photo cover:

Pål Keim Olsen
palkeim@ntnu.no

We only use environmentally certified printing houses.

Akademika Publishing
NO–7005 Trondheim,
Norway
Tel.: + 47 73 59 32 10
www.akademikaforlag.no

Publishing Editor: Lasse Postmyr (lasse.postmyr@akademika.no)

Preface

This publication contains all the papers presented at the 23rd Nordic Insulation Symposium (Nord-IS 13) held in Trondheim, Norway, June 9 - 12, 2013. Before acceptance, the abstracts and then the 44 received papers were reviewed by members of the Organizing Committee and the Advisory Council with respect to relevance and quality. ***Challenges arising from use of HVDC*** is selected as the preferential subject for Nord-IS 13. All subjects dealt with at previous Nord-IS are, however, included. This means for example ageing and breakdown phenomena, condition assessment and measurement techniques.

The Symposium is an interdisciplinary forum for open discussion of ideas, research results and practical experiences related to application of insulating materials and systems in electrical power apparatus. It is addressed to PhD students, researchers and engineers working within academia, research institutes, power industry and power utility companies. Nord-IS is held every second year in one of the Nordic countries; Norway, Denmark, Sweden and Finland. Young researchers are particularly encouraged to contribute. English is the working language of Nord-IS and participants from outside the Nordic area are welcome.

I would like to express my gratitude to all those who have worked hard and contributed in many different ways to make Nord-IS 13 possible. Thanks are due to the members of the Organizing Committee and the Advisory Council for their cooperation in planning of the program and acting as session chairmen during the Symposium. I am particularly indebted to PhD fellow Pål Keim Olsen for his invaluable efforts as secretary, executing all the work associated with Nord-IS 13. – Last but not least I would like to thank all authors and participants for making Nord-IS 13 a success.

Trondheim, May 2013

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History

1: 1968 - Nord-PD in Västerås, Sweden
2: 1970 - Otnäs, Finland
3: 1972 - Trondheim, Norway
4: 1974 - Kollekolle, Denmark
5: 1976 - Saltsjöbaden, Sweden
6: 1978 - Vaasa, Finland
7: 1980 - Røros, Norway
8: 1982 - Odense, Denmark
9: 1984 - Kungälv, Sweden
10: 1986 - Hanaholmen, Finland
11: 1988 - Trondheim, Norway
12: 1990 - Lyngby, Denmark
13: 1992 - Västerås, Sweden
14: 1994 - Vaasa, Finland
15: 1996 - Bergen, Norway
16: 1999 - Lyngby, Denmark
17: 2001 - Stockholm, Sweden
18: 2003 - Tampere, Finland
19: 2005 - Trondheim, Norway
20: 2007 - Lyngby, Denmark
21: 2009 - Gothenburg, Sweden
22: 2011 - Tampere, Finland
23: 2013 - Trondheim, Norway

PROGRAM NORD-IS 2013

Sunday, June 9, 2013

17:00-19:00 Registration at NTNU. Mounting of Posters

Monday, June 10, 2013

08:00 - 09:00 Registration and mounting of posters

09:00 - 09:10 Opening of symposium: Welcome to NTNU by head of department prof. Olav Fosso

09:40 - 10:00 Coffee break and mounting of posters

10:00 - 12:00 Session 1 - HVDC Challenges

Chair: Bjørn Sanden, StatNett (Norway)

12:00 - 13:00 Lunch

13:00 - 14:15 Poster Session 1 and coffee break

14:15 - 15:35 Session 2 - Breakdown and Ageing of Solid Insulation Systems

Chair: Hans Edin, KTH (Sweden)

15:30 - 16:00 Coffee break

16:00 - 17:00 Session 3 - Breakdown and Ageing of Solid Insulation Systems

Chair: Jørgen Blennow, Chalmers (Sweden)

19:00 - 21:30 Symposium opening banquett at Banksalen, Trondheim city centre

Tuesday, June 11, 2013

08:00 – 09:00 Mounting of Poster Session 2

09:00 - 10:50 Session 4 - Condition Assessment and Test Procedures

Chair: Petri Hyvönen, Aalto University (Finland)

10:50 - 11:00 Coffee break

11:00 - 12:00 Poster Session 2

12:00 - 13:00 Lunch

13:00 – 16:00 Technical visits – NTNU/SINTEF laboratories and Leirfossen Hydro Power Station

18:30 - 19:30 Greetings from the Mayor's Office and Concert in Nidarosdomen

19:30 - 20:30 Tour Nidarosdomen

Wednesday, June 12, 2013

09:00 - 10:30 Session 5 Breakdown and Ageing of Liquid Insulation Systems

Chair: Henrik Hillborg, ABB Corporate Research (Sweden)

10:30 - 10:45 Coffee break

10:45 - 12:05 Session 6 Gaseous and Impregnated Insulation Systems

Chair: Rolf Hegerberg, Sintef Energy (Norway)

14:45 - 15:00 Closing of the symposium

Poster Session 1

Poster Session 2

POSTER SESSION 2

Behavior of Rubber Materials under Exposure to High Electric Fields

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Technical University of Denmark, Department of Electrical Engineering
Kgs. Lyngby, Denmark

Abstract

The effect of high electrical stress on rubber materials is investigated by performing breakdown tests and tracking resistance tests on selected samples. The study is focused on the relationship between the dielectric strength and the thickness of the samples, as well as the influence of the interfaces between different layers of material. Tracking resistance tests are also performed on the rubber material. The purpose is to provide a complete study of the applicability of the rubber material in thunderstorm environments.

1. Introduction

In the recent years, new technologies have been developed to increase the efficiency of wind turbine blades, some of which involve the use of rubber materials in the blade structure. Amongst these technologies, the deformable flaps aim at reducing the load on the blade, thus alleviating the fatigue strain on the whole wind turbine [1]. This is achieved by installing a rubber flap in the trailing edge of the blade (Fig. 1), and controlling its deflection using a compressed-air system. Once installed in the blade, the rubber flap will be subjected to severe ambient conditions. This paper is focused on the effect of high electric fields on the electrical performance of rubber materials.

During their lifetime wind turbines are repeatedly exposed to high electric fields from thunderstorms, which degrade progressively the insulating properties of the blade materials [2]. The interaction between the thunderstorm electric field and the fiberglass material usually used in wind turbines has been widely studied, [3]. However, the behavior of the rubber material in a thunderstorm environment is not fully known and therefore needs to be assessed.

The IEC standard on lightning protection of wind turbines [2] defines the tests to be performed in wind turbines to reproduce the effects of direct lightning strike. However, there is a need for tests aimed at assessing the effects of repeated high electric field and discharge exposure on the insulating materials of the blade. In this study, the rubber behavior under high electric fields is investigated by performing breakdown and tracking resistance tests. These methods have been used previously to evaluate the performance of blade insulating materials against lightning [3], [4]. The criterion used to evaluate the tests results on fiberglass was to affect the material as it was seen in blades in service.

Samples of four different rubber materials have been subjected to breakdown and tracking tests. The samples and setups used in the tests are described in section 2. Section 3 summarizes the test results, comparing the different rubber materials. The relationship between the breakdown strength and the thickness of the samples and the influence of the interfaces between the layers of material are also investigated and described in this section. Finally, the outcome of the tests is discussed in section 5, where the suitability of rubber materials in wind turbine blades is discussed.

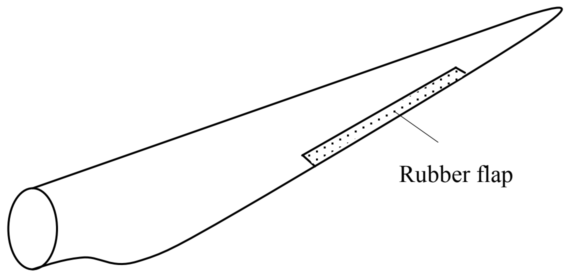

Fig.1 – Wind turbine blade equipped with a rubber flap system, installed on the blade trailing edge.

2. Materials and tests description

Four different rubber materials are used for both the breakdown and the tracking resistance tests. These materials are a representative selection of different types of rubber:

- Santoprene 121-73W175 (Polyolefin elastomer)
- Silicone rubber 5060-5
- PUR 8070-3 (Polyurethane)
- EPDM 2165-1 (Ethylene Propylene Diene monomer (M-class))

2.1. Breakdown strength tests

The specimens used for this test are square shaped, with a side length of 100 mm. Each material has been tested with a thickness of 1, 2, 3 and 4 mm.

The sample is placed between two electrodes inside a container filled with silicone oil (Fig. 2). The upper electrode is spherical, with a diameter of 12.5 mm, and it is connected to the high impulse voltage generator. The lower electrode is cylindrical with rounded edges, with a diameter of 70 mm, and is connected to ground. The purpose of the silicone oil is to increase the electrical breakdown of the media around the specimen, in order to prevent side flashovers.

The test follows the procedure described in [5]. It consists of applying a high voltage impulse with a rise

time and decay to half value of 1.2 and 50 µs respectively, according to [6]. The test starts at relatively low voltage, where there is no risk of breakdown, and it is increased progressively until the breakdown of the material is reached.
This procedure is repeated 6 times. Each time, the peak value of the voltage impulse that produces breakdown and the peak value of the withstand voltage previous to breakdown are measured. The breakdown and withstand voltages of each material found in section 3 correspond to the average value of the measurements.

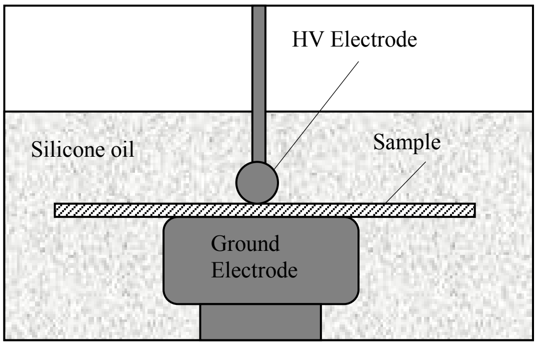

Fig.2 – Breakdown test setup: rubber sample placed between the high voltage and ground electrodes, inside a container filled with silicone oil.

2.2. Tracking resistance tests

The setup arrangement and the test procedure follow the standard setup described in [7]. The specimens are mounted on an insulating support, which stands at an angle of 45 degrees from the horizontal. Two electrodes are placed on the top and the bottom of the sample, connected to high voltage and ground respectively (Fig. 3). The specimens are arranged in sets of 5 samples. Each sample is 50 x 120 mm, with a thickness of 2 mm (Fig. 4).

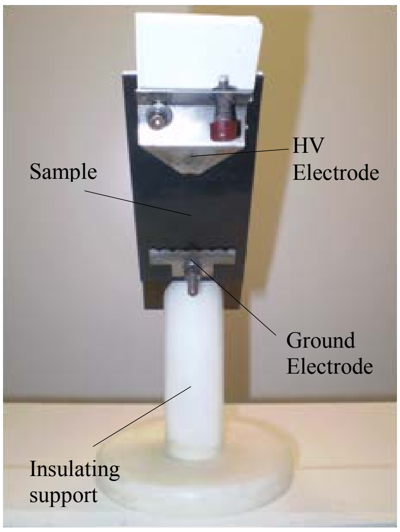

Fig.3 – Tracking resistance test setup. Sample of rubber material mounted on the insulating support with the electrodes.

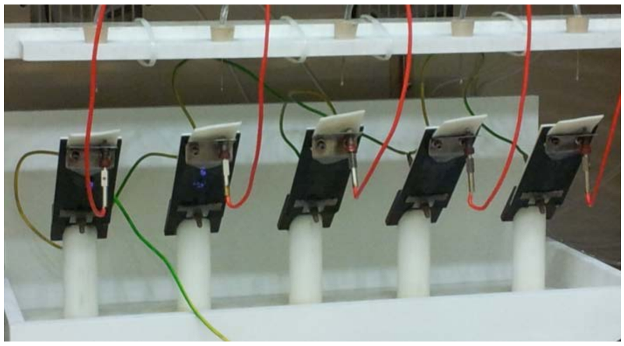

Fig.4 – Tracking resistance test setup. Set of 5 samples mounted on the supports.

The procedure follows the Method 2, according to [7]: stepwise tracking voltage. It mainly consists of applying a sequence of AC voltage levels across the sample while a contaminant solution based on NH_4Cl is flowing over the sample lower surface. The initial voltage is chosen in such a way that no sample will fail during the three first steps, and is increased by 250 V every hour. The end-point criterion used in this test is "End-point criterion A: the value of current through the specimen exceeds 60 mA". In order to determine when the current is over the maximum value allowed, a fuse is installed in the HV circuit of each sample.

3. Tests results

This section summarizes the results of the breakdown strength and the tracking resistance tests on the rubber materials.

3.1. Breakdown strength tests

The breakdown strength tests were performed on 6 samples of each thickness, for the four different rubber materials. The average breakdown and withstand voltages for each material and thickness are displayed in Fig 5.

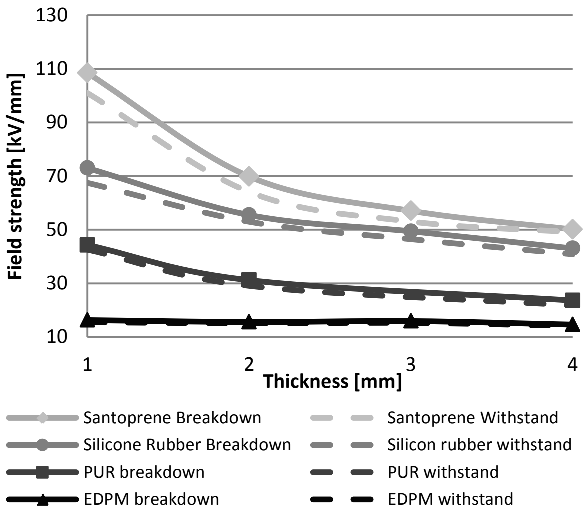

Fig.5 – Breakdown and withstand field strength of the tested materials, for thicknesses from 1 to 4 mm.

According to the test results, the Santoprene material presents the highest breakdown field strength of 110 kV/mm, followed by silicone rubber showing 72 kV/mm. It is also observed that the breakdown strength decreases when increasing the thickness of the sample. This can be explained by the so-called volume effect, where an increase of the material thickness involves a higher probability of impurities or microscopic defects. These inhomogeneities, normally small particles and air bubbles, enhance the electric field around or inside them, and lead to an earlier breakdown of the material. The volume effect can be found in all the tested materials except the EDPM. Considering that this material shows a very low breakdown strength, the negative influence of possible impurities is less dominant.

In order to study further the volume effect and the influence of interfaces, additional tests were performed to Santoprene, the material showing the highest breakdown strength. These tests consisted of testing two layers of material together. The results were compared to the breakdown strength of a single layer with the same total thickness and with the theoretical calculation of the breakdown strength obtained from the independent layers.

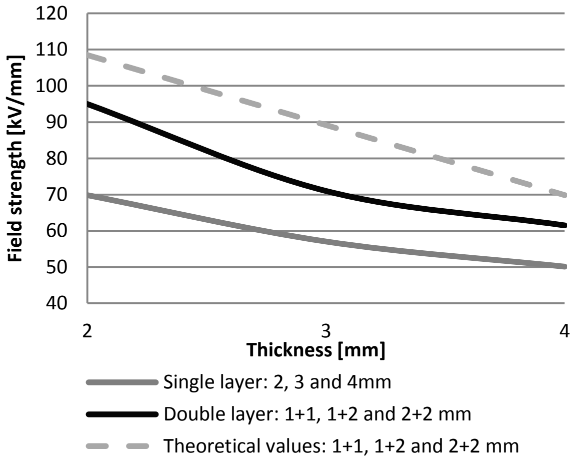

Fig.6 – Comparison of breakdown field strength between single-layer setup, double-layer setup and theoretical values for the double layer setup calculated from the breakdown strength of the independent layers.

The test reveals that the double-layer setup has higher breakdown strength than the single-layer setup. At a first glance, this may be surprising, since we have an additional interface in the material. On the other hand each layer of the double-layer setup presents fewer impurities per volume than the thicker single-layer, which makes the result more plausible. It is also found that the breakdown strength of the double-layer setup is lower than the value calculated from each independent layer. This fact indicates that in the double-layer setup, the breakdown occurs first in the weakest layer, directly followed by the other layer. Therefore, the weakest layer determines the breakdown of both layers. This phenomenon is more evident in the case of mixed thickness (1+2 mm), where the difference between the calculated and the actual breakdown strength of the double-layer is greater.

3.2. Tracking resistance tests

The tracking resistance tests were performed on sets of five samples of the four different materials. Table 1 summarizes the results. The initial and the final voltages are the voltage level applied to the samples at the beginning of the test and the voltage level where the first sample failed, respectively. The classification of the material according to [7] corresponds to IEC Class – Method used to apply the voltage/end-point criterion/ maximum level of voltage withstood.

Table.1 – Tracking resistance tests: classification of the material according to the test results.

Material	Initial voltage [kV]	Final Voltage [kV]	IEC Class
Santoprene	3.5	4.5	2A 4.25 kV
Silicone rubber	3	4.5	2A 4.25 kV
PUR 8070-3	3	4.75	2A 4.5kV
EPDM 2165-1	1	1	Failed

The PUR material reached the highest voltage level before failure, followed by the Santoprene and silicone rubber, which show similar results. The EPDM material failed at the lowest level of voltage, and it is therefore out of the range of the IEC classification.

The end-point criterion chosen for the tracking tests depends only on the level of current flowing through the sample. Still, it is relevant for this investigation to look at the erosion of the samples after the tests, since it varies considerably in materials that withstand a similar level of voltage. Figs. 7 to 10 show the surface erosion of the samples after the tests.

Fig.7 – Surface erosion in Santoprene rubber material after the tracking resistance tests. Samples 1 and 3 failed.

Fig.8 – Surface erosion in Silicone rubber material after the tracking resistance tests. Sample 1 failed.

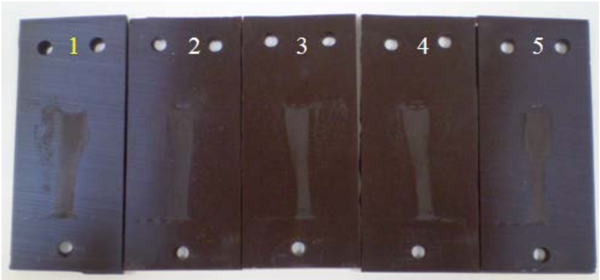

Fig.9 – Surface erosion in PUR rubber material after the tracking resistance tests. Sample 1 failed.

Fig.10 – Surface erosion in EPDM rubber material after the tracking resistance tests. All samples failed.

It is seen in the pictures (Figs. 7-10) that all the samples show a matt appearance between the electrodes. However, this band is different in each material, and only some materials present a deep track. The Santoprene and EPDM materials have a narrow track. The Santoprene samples present erosion only next to the bottom electrode, while the EPDM samples have severe erosion in the whole path between the electrodes. The silicone and PUR materials have a wider dry band and no significant erosion. A failed sample of each material is shown in Fig. 11.

Fig.11 –The surface erosion (marked in yellow) and dry band can be compared in failed samples of each material. From left to right: Santoprene, Silicone rubber, PUR, EPDM.

4. Discussion

In this paper, the assessment of materials is done by comparison of the tests results regarding break down and tracking. Though being relevant for wind turbine flap application, the tests themselves do not directly provide information to determine if the material is suitable for the flap application with respect to interaction with lightning discharges. The breakdown strength tests show that the Santoprene material performs better than the other rubber materials, and its performance is comparable to the fiberglass materials used in wind turbine blades [3]. It is also observed that the thickness of the sample has a significant impact on the breakdown strength of the material due to the volume effect. Regarding the tracking resistance tests, all rubber materials reach similar levels of voltage, except the EPDM material, which failed at the beginning of the tests. Furthermore, significant differences in erosion are observed in the materials that withstand the same level of voltage. Finally, it has to be considered that a rubber flap installed in a blade in service will be subjected to mechanical fatigue. Therefore mechanical tests should be done with the tested samples in order to evaluate how the erosion due to tracking affects the performance of the material in general.

5. Conclusions

Breakdown and tracking tests were performed on a selection of rubber materials following the same procedure as in GFRP materials for wind turbine blades. The tests results show that the Santoprene material performs better than the other materials, and has comparable properties to the fiberglass material used in blades with respect to tracking resistance and breakdown strength. Therefore, it can be considered as a suitable candidate for wind turbine blade flaps application, regarding its performance in interaction with lightning discharges.

6. References

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