Optimisation of surface protection by super hydrophobic surfaces for medium sized distribution-transformers or inductive components in outdoor areas

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Abstract

An essential factor for the electrical performance of inductive components are multi-stress conditions like contamination, moisture and electrical stress during operation. Unfortunately this implies an increasement of the ageing speed of insulations and other components. To extend the lifetime of such high voltage insulating systems it is of particular importance to reinforce the surface of materials. They need to be able to deal with contemporary electrical and climatic stress. Since the development of surface modifications, hydrophobic insulating surfaces, in function similar to the "Lotus Effect", can be now created. In the following study the investigation of the ageing process of transformers and inductive components while working with modified insulating surfaces is carried out.

1. Introduction

Transformers are irreplaceable for the electric power supply. Without them the whole industry stops. The entire industry as well as every human is reliant on power supply by means of transformers, which are known for 100 years and are in world wide use. The fundamental construction of iron core, winding and insulation didn't change at all since then. The different applications, on the one hand from high power distribution and transmission, on the other hand to the ultimate consumers in electrical devices, in electrical transmission caused a variety of types and constructions. No other component is determined by so many different requirements and parameters like the transformer. This calls for a high development effort at the construction of the insulation. Not only the claim for low losses, low weight, small dimensions and high reliability grew steady, also the conditions to environment-friendly insulations became more sophisticated. Likewise the demand on higher resistances to environmental influences, like humidity or dirt increased, because they mean premature aging, debilitation of the insulation and thus a failure for every transformer. Especially those transformers are exposed to such conditions that are used in the outdoor area or in rough industry environments.

2. Requirements concerning resistance against environmental stress

Transformer type, market segment	**Requirements in the past**	**Requirements today**
Small transformers conform VDE 0570 for industrial electronics	IP 00, built in a safe housing	High power density, ventilation with (damp and polluted) ambient air required
Inductive components for the automotive section	Encapsulated installation, low heat development at low power density	Installation in exposed areas, cooling with ambient temperature
Large- and distribution transformers conform VDE 0532	Oil-immersed transformers used to have housings	Environment-friendly cast resin transformers without housing for optimal heat removal and compliance with safety distances
Transformers and chokes for railway technology	Encapsulated installation, low heat development at low power density	High, because of high power density caused by cooling with ambient air or airflow

Linear stators for roller coasters and new impulsion concepts	These components for that application are new	Mounting safe areas e.g. in or as rails, cooling with ambient air
Insulation transformers for lightening protection conform VDE 0855, part 300, attachment A	Oil-immersed transformers used to have housings	Environment-friendly cast resin transformers without housing for optimal heat removal and compliance with safety distances

table 1: Requirements concerning resistance of transformers and inductive components in different market segments in the past and today

3. Conventional protection

3.1. Protection against environmental influences

Large transformers and inductive components, e.g. automotive technology, are used in outdoor areas and industrial environment. Hence these transformers need a protection against environmental influences like humidity and dirt. Up to now, this protection is enabled by housings with adequate IP protection class. For high IP protection classes, the housings are properly sealed.

The sealing cumbers the heat removal to the outside, because there can't be any interchange of heat by moved air. The heat removal has to be done by the housing. Large oil-immersed transformers are equipped with gills on the housing, to enable the dissipation of heat. The oil is pumped in a circulation and can remove the heat. Oil-immersed transformers are more and more replaced by sediment isolated transformers for environmental reasons, because certain protective measures in case of leakage of the liquids can be dropped.

Potted or varnished inductive components without housing are easily cooled by ventilation and it doesn't need any complicated bulkhead receptacles for the connections. It's easier to redeem the needed air distances for high voltage transformers without housing. The connections are easily hosted on the insulating surface.

The construction without housing has no noise growth by vibrations or resonance vibrations of the housing walls. Transformers without a housing have many advantages (see table 2), thus the question arises: How can the lifetime of inductive components be increased by an efficient dirt- or humidity protection

Fig. 1. Moistened housing

3.2. Advantages and disadvantages of transformer housings

Transformer type	Possible housing	Advantage	disadvantage
Small transformers conform VDE 0570 and inductive components for the automotive section	Plastic housing made of PA 6.6 IP 54 up to 500 VA as default size conform DIN 41305	Cheap, stock component	For special sizes outside of the norm DIN 41305 no housings are available
Large- and distribution transformers conform VDE 0532	Default metal housing IP 54	Cheap, easy to produce	Bad heat removal, problems with the insulation, required distances can only be met by stretched dimensions
Transformers and chokes for the railway technology	Not possible, because of the cooling		
Linear stators for roller coasters and new impulsion	Individual metal- and/or plastic housing IP 65	Can be adjusted precisely e.g. to	Bad heat removal, problems with the insulation, very expen-

concepts		the rails	sive and technical costly
Insulation transform-ers for lightening protection conform VDE 0855, part 300, attachment A	Plastic housing IP 54	Cheap, easy to pro-duce	Bad heat removal, problems with the in-sulation, re-quired dis-tances can only be met by stretched dimensions

table 2: Overview – housing advantages and disadvantages for transformers with high protection class. All types of housing require a special termination technique, e.g. cable glands, sealing and special insulations. All pot housings form an inner interface between housing and potting medium. At metal housings you can find air between the transformer and panel, because of observance of the distances. This air insulates (similar to double glass windows) the heat.

4. Lotus Effect

An effective protection against humidity and as a cause the ageing of transformers isn't researched properly. Previous solutions that reach high IP protection classes and grades, base on individual solutions like e.g. several protection layers made of polymer varnishes. But these layers meet just parts of the requirements for resistance against humidity, mechanical and electric tensions, electric fields and aggressive dirt. Furthermore the problems of ageing aren't researched yet.

In the past years "Lotus Effect" coatings caused euphoria. There are products for glass plate sealing of the company Nanogate Coatings Systems, Saarbrücken, lotus effect glasses of the company Ferro Corp., USA, burning-in coating for metals from Unicopie, Düsseldorf, plasma polymer coatings, Fraunhofer Institut für Fertigungstechnik, and bonding improvement of polyamide on copper from Fraunhofer Institut für Silikat-Forschung.

So far these substances didn't prevail for the usage of electrical engineering. The producers of insulation materials and insulators for electrical engineering are very cautious with statements about the operation of the lotus effect in this section, because of a lack of persuasive tests in laboratories and field trials from practice, which would prove a long-term performance of the effect. For epoxy cast resin systems the lotus effect could mean a distinct improvement of the hydrophobic characteristics. So far there is no research of polyurethane objects, although these PU-cast resins have been improved permanently in the past years.

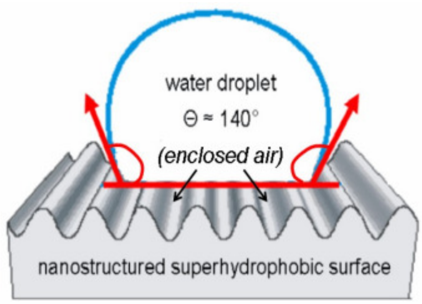

Fig. 2. schematic diagram of a self cleaning super hydrophobic surface; [9] Study on durability…

5. Experiments

The goal is to put cast resin dry transformers or dry transformers or transformers without housing in a high IP protection class conform to EN 60529 or in a high dirt class conform to EN 50155 by using an innovative way of surface treatment. Especially in outdoor-, industrial- and automotive areas with very distinctive pollution layers, the lotus effect can be useful. Like this, the combination of ageing resistant insulation materials and a hydrophobic surface, caused by the lotus effect, can contribute to an improvement of the whole insulation system.

To be able to measure the deterioration of insulating materials, caused by infiltration of moisture, we built capacitors with electrodes. Between the electrodes you can find the insulating material that is to be surveyed. To get comparable values, we first examined a test item without any manipulation.

The following problems with the different test types occurred:

- test items with knurled nuts as electrodes are not adaptive, because of field cambers at the edges
- test items with Rogowski profile are not eligible either, because the homogeneous field requires very high voltages, to receive measured values

- even test items with needlepoint as electrodes show discharges on the surface

Following these results, we decided not to use test items, which are capacitors or pairs of electrodes. Instead we started to do tests with real transformers.

To measure the quality of the surface protection, tests are made before and after the moisture experiments. Checked are:

- leakage current
- partial discharge
- insulation resistance
- disruptive discharge between primary and secondary

Good test items show no distinction before and after the moisture experiments.

6. Results

The coating experiments with hydrophobic silicon varnishes showed very good results regarding the hydrophobia, however the bonding of the coating to the component was not satisfying. Thus the question about a long-term stability didn't occur yet. The experiments with metallic surfaces are not executed at the present moment. PU and PE cast-resins tend to have a decent adhesion without additional resources. We came to think

- to use a cast-resin, which makes an additional coating unnecessary
- to use a cast-resin as coating

7. Outlook

Some cast-resins show good hydrophobic characteristics. Unfortunately the other mechanical and electrical qualities don't show the same good attributes most of the time. These cast-resins can only be used as coatings. We also still lack experiments about the simultaneous properties on different surfaces, like iron, copper and polymeric surfaces.

Inductive components with super hydrophobic coatings show better results during multi-stress than unprotected components:

- low leakage current
- low partial discharge
- reduced absorption of water

The long-term performance is still unknown though.

8. Literature

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