Abstract: The aim of this paper is to report the preliminary results on the investigations performed to determine the origins and causes of heavy damages occurred under service on some static inverter module resistances. The obtained results indicate that the values of the electric and dielectric characteristics of the cooling liquid are still very good. Only the dissipation factor values show a severe increase, which is however not a limiting factor for the application in the static inverters. From the preliminary investigations, it seemed that the failure origins are due to a free burning arc between two resistance lamellas. Furthermore, some recommendations were suggested for the investigations follow up.

INTRODUCTION

Static Inverters are auxiliary power supplies for electrical equipment such as compressor, fan, lighting, air conditioning, etc. Current mode control provides stable operation into any load, including the non-linear and dynamic loads seen in critical applications. For high voltages applications, the loading resistances their self must be able to withstand high voltage. Moreover, those resistances must be constructed to dissipate the heat generated by current flow and voltage drop. This requires a certain physical size or special means for cooling.

The particularly shaped resistances concerned in these investigations consist of steel wiring sheet. For the normal operations purposes, those resistances as well as the static inverter module are filled with an ester liquid in order to dissipate heat and to insulate the construction units against each other electrically. During service, a strong overheating of the wiring resistance occurred, whereby damage of the resistances arose and decomposition of the insulating liquid took place, what by its stinging smell was noticeable among other things. To quantify origins of those defects, various investigations on the electric and dielectric properties as well as the gassing tendency of the deteriorated insulating liquid samples have been performed. The electric breakdown and dissipation factor investigations were performed for assessing the deterioration severity of the insulating liquid. In order to examine whether a relation exists between the severity of the damage and the remaining resistance value of the wiring resistance, the later was examined with an automatic RCL-measuring instrument of the type PM6303A manufactured by the company Philips/Fluke. Examination of such powder revealed that no solid metal parts could be found. In order to examine whether a relation exists between the severity of the damage and the remaining resistance value of the cooling fluid (an ester liquid) have been investigated.

OBSERVATIONS OF THE DAMAGED RESISTANCES

The damaged resistances as well as their locations and working environment were first optically examined. It was first observed on the defective resistances that, between the lamellas, spherical black deposits were formed. These were easily out-broken and possessed a resistance of a few ohms (approx. 2-3 Ω). By crushing these deposits in a mortar, a black, graphite-like resplendent powder was obtained. Examination of such powder revealed that no solid metal parts could be found. A direct relation of the damage extent could therefore not be determined.

INVESTIGATIONS ON THE INSULATING LIQUID FROM THE DAMAGED RESISTANCES

Loss factor, relative permittivity and breakdown strength

In order to quantify the extent of the failure/damage and origin of the arcing, the dielectric properties of samples of the cooling fluid (an ester liquid) have been investigated. Measurements of the water content, the breakdown voltage, the dissipation factor as well as the relative dielectric constant at 20 as well as 80°C were performed on samples of the insulating liquid (ester liquid) from the damaged resistance. The temperature variation for the investigations was chosen in order to simulate normal operating conditions as well as critical situations in the resistance. An average temperature of 80°C was determined during preceding temperature measurements under continuous operation. During operation of liquid-filled equipments, the insulating liquid ages, due to:

- the admission of oxygen and humidity from the environment,
- the increased temperature and,
- the presence of catalysts (e.g. copper, zinc or other metals, which are contained in the equipment).

The taken up oxygen reacts with the liquid. First peroxides, and thereafter oxidation products such as alcohols, ketone, acids and esters and finally high-molecular connections form, which are solved in the insulating liquid [1]. Thereby all the dielectric properties of the insulating liquid such as disruptive strength and dielectric dissipation factor are worsened. Insulation life is normally determined by measuring the time to breakdown. Doing this in "real time" would have been rather exhausting, given that the insulation systems are expected to last several decades before failure occurs. It is therefore appropriate to perform a sealed vessel ageing procedure, whereby the ageing process is accelerated in laboratory tests in order to greatly reduce the lifespan of liquid insulation. The results of the investigations are summarized in figures 1 to 3. A sealed vessel ageing procedure is more rapid, less expensive, and provides samples with a controlled thermal history. It is also more amenable to the exploration of the materials and their condition during ageing [2].

This is done by placing the insulating liquid samples in a convection oven at 100°C and aging them for extended period of 2,000 h, in presence of air/oxygen. The procedure involves aging the new liquid samples within sealed vessels, and requires that the tested samples include all other significant materials used in the system. Also, for comparison, the test program includes samples of the insulating liquid used in the present system. To simulate the effects of metallic components in the system, metallic catalysts (each 3 g/l zinc, copper, aluminum, and iron of cuttings) were attached in a filter paper and immersed in the liquid. Earlier investigations in our laboratory have shown that by this accelerated ageing procedure, the electrical and dielectric properties of the insulating liquid worsen strongly and are comparable with an insulating liquid originating from a 30 years operation period of transformer [3]. The insulating liquid samples from the damaged resistances were agitated before each test, so that possible dirt/particles therein in it could distribute itself homogeneously. The water content of the insulating liquid sample was determined with an automatic Karl Fischer Coulometer 652 [4] manufactured by the company Metrohm and was found to be 335 ppm, which lies far below the water saturation limit (the water saturation limit of the insulating liquid at ambient temperature is approximately 2700 ppm).

The AC dielectric test experimental set-up can be found in our previous contributions [5]. From the breakdown voltage measurements according to IEC 61099 [6], average values of 56.1 kV and 55.6 kV were respectively obtained at 20°C and 80°C. These values lie above the standard limits, which require breakdown strength of 45 kV for ester liquids in the delivered state. The measurements of the dissipation factor tanδ and the permittivity εr were carried out using a Schering-Bridge (with a sensitivity 5 x 10^{-7}) at a line frequency of 50 Hz. As shown in Fig. 2, the relative dielectric constant εr both at 20 and 80°C is around 3.2 which is in the typical range for the investigated ester liquid. The dissipation factor tanδ (Fig. 3), rises from 207.68 x 10^{-4} at 20°C to 406.24 x 10^{-4} at 80°C and lies thereby above the limit required by the IEC 61099 [6] indicating a greater extent of contaminations in the liquid.

Gassing behavior under thermal stress

The thermal stress in a liquid specimen has been simulated in a set up shown in [7]. It consists of a Borosilicate-glass vessel and a Teflon-cover with clamps to hold the heating wire. The heating wire is made of constantan, the characteristics of which can be found in [8].
The temperature around the heating wire is assumed to be constant and is measured with a NiCrNi-temperature sensor. The heating current is supplied from a short circuit transformer and the temperature of the wire can be regulated by an ammeter connected to the primary and secondary circuits. A funnel-shaped Teflon device over the heating wire allows the generated gases to go directly to a burette where they can be measured. This test set up allows the local controlled heating of the liquid to over 1000°C [8, 9]. By a local thermal stress of the ester liquid it was found that, first visible gassing arises starting from a certain temperature. This behavior is illustrated in the Fig. 4.

The aim of this investigation was to determine the breakdown voltage between the lamellas and also to see if there are preferential points for the breakdown to occur. First of all, two resistance lamellas were isolated against each other with a Teflon mounting plate and the investigations performed at line frequency voltage (Fig. 6). Twelve tests have been performed leading to a mean value:

\[ U_B = 16.44 \pm 0.578 \text{ kV} \] (1)

The results showed that, arc footprints were freely distributed on the lamella surface as long as the distance between lamellas is kept constant. On the damaged resistances, most damages arose in the region of the connections letting believe that mechanical problems had reduced the inter-lamellas distance in those regions to induce the failures. Indeed, within the range of operating voltage \( U = 1.6 \text{ kV} \), arcing should have take place only because of mechanical problem.

**Breakdown strength between two resistances lamellas**

**Influence of air bubble supplied between lamellas on the breakdown strength**

In order to quantify the influence of gas bubbles on the breakdown voltage, before the measurement some gas bubbles were injected between the isolated lamellas with the help of a syringe. Table I summarizes the investigations results. The breakdown voltage is, as expects, lower than that obtained in equation (1). In the second column, the presence of a free burning arc is indicated.
The most important obtained results can be summarized as follows:

1. Investigations on the cooling liquid from the damaged resistances and the comparison with new and accelerated aged insulating liquids indicate that the values of the electric and dielectric characteristics of the cooling liquid are still very good. Only the loss factor tanδ show an important increase indicating a greater extent of contaminations in the liquid.

2. Investigation of the gassing behavior of the cooling liquid due to thermal load showed that, visible gassing takes place only at high temperatures of 350 - 400°C. The produced mass of gas depends thereby on the temperature as well as on the load duration. From this it can be concluded that at the temperatures arising in the normal operation of the resistances no visible masses of gas, which affect the operation can be produced. Also at a temperature of up to 1000°C no stinging smell, as it arose with the damaged resistances, could be determined.

3. Under normal operation conditions, the breakdown voltage between the lamellas was measured to about 16 kV. This means a large security in comparison to the liquid molecules were thus decomposed by rupture of the chemical bonds between the atoms increasing contaminants and so to speak the dissipation factor. The massive generation of gases intensified partial discharges and initiated further breakdown in highly stressed regions nearby.

However, one should note that every failure can occur alone, or in combination with other failures. Further investigations, such as the inception of a free burning arc between two lamellas, influence of the spherical black deposits on arcing behavior, are therefore necessaries to draw more general conclusions. In this connection, the authors are engaged in a study to further investigate those points, and they expect to publish their results in a future work.

REFERENCES


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