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Investigation of failure of high voltage bushing at power transformer

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ABSTRACT

In this paper, bushing-breakdown was identified as one of the main causes of transformer failure that resulted in a fire outbreak in July 2015 at the Gadong Power Station, Brunei Darussalam. To perform the investigation, three specimens from the burnt pieces were collected, which were white ash, bushing housing ashes and solid remnants from the burnt site. Both JSM-610F FIELD Emission Scanning Electron Microscope (SEM) and Energy Dispersive X-ray Spectroscopy (EDS) were used to obtain the electron images, and to analyze the types of elements present in the specimens. In addition, software simulations for the high voltage bushing failure were carried out using COMSOL Multiphysics Software for different oil levels, and the obtained results have been summarized. Finally, it is comprehended that fire outbreak happened due to leaking of the insulating oil in the high voltage bushing and loose tighten of the sealing part of the cable termination boxes.

1. Introduction

In July 2015, a fire broke-out in one of the Power Stations in Brunei Darussalam. Immediately after the fire incident, an external inspection was carried out, which confirmed that the insulating oil was leaking in the B-phase HV cable box where the fire initiated at the top end of the stress cone and the top part of the bushing. As a result, the top section of the cast resin housing fragmented into several pieces as shown in Fig. 1. The insulation on the XLPE cables at the location of the fire breakout disintegrated and white ash was found on the broken housing. The possible fire breakout was identified to be the top part of the bushing, cable termination and oil contamination. At that point, to validate the external findings, and to identify the cause of the fire, a thorough scientific investigation was called for. This paper presents different steps taken during the investigation, and the pertinent findings of this study.

In a power transmission system, improperly designed and/or irregularly maintained electrical equipment can result in electric breakdowns and flashovers, and in this case, bushing was identified as one of the vulnerable components [1]. Bushing is an insulating device that supports any electrical conductor by providing a point of interface such that the current can pass to and from electrical equipment such as transformer and circuit breaker [2] [3]. Bushing failure can cause havoc in the power transmission systems, which are generally designed to operate at high voltages in order to reduce resistive losses generated by high currents.

It has been found that 44% of transformer failures are related to bushings and windings [4]. This statement has further been supported by a survey, prepared for the Australian CIGRE in the year 2002–2004, where 90% of the transformer failures initiating fire were found to be caused by a bushing or a cable box termination failure [5]. Another CIGRE survey stated that 10% of transformer failures were caused by bushing damage, followed by a catastrophic consequence [6]. The authors in Ref. [7] stated that about 90% of bushing failures in power transformers were caused by moisture entering the bushing through leaky gaskets or other openings, and most outages due to bushing failures could be prevented by periodic inspection.

Based on all the aforementioned evidences, the focus of the study presented in this paper was suspected due to bushing failure. Here, an experimental investigation on the chemical content of the bushing housing ash, burnt solid material, and the variation of the insulating oil-level followed by a simulation study were interpreted to identify the cause of the fire.

1.1. Experimental results

In order to carry out the investigation, three specimens were

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Fig. 1. Broken parts of B-phase HV cable termination and bushing.

collected from the fire location, and these were white ashes, bushing housing ashes and solid remnants from the burnt site. For the experimental setup, in the first step, the collected specimens were carefully cut into appropriate pieces to be properly fitted under the JSM-610F FIELD Emission Scanning Electron Microscope (SEM). These specimens were then coated with carbon by using the *Auto Carbon Coater*, the equipment that provide necessary preparation for non-metallic and non-conductive specimens for SEM analysis [8,9]. Subsequently, electron images of these carbon-coated specimens were acquired using the SEM, and further elemental analysis of the scanned images were carried out using *Energy Dispersive X-ray Spectroscopy* (EDS) [8]. It is worth noting that the backscattered electron images of the specimens, obtained from the SEM, display compositional contrast that results from different atomic numbers of the elements in the specimens and their distributions, while the elements in the specimens were further identified with the help of EDS.

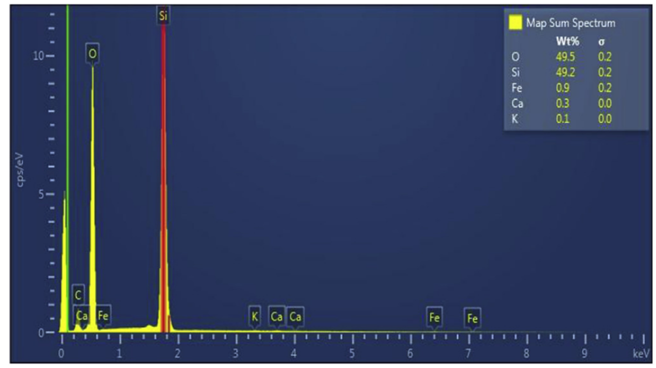

Fig. 3. Map sum spectrum analysis of scanned specimen.

Specimen I-White Ash: The electron images of the white-ash specimen, are shown in Fig. 2. The presence of different elements in the specimen is distinguished by observing the difference in colors on the electron images.

Green, blue and red colors on the electron images identify Silicon (Si), Carbon (C) and Oxygen (O) elements, respectively. Fig. 3 represents spectral analysis of elements that are identified in the scanned images, obtained with the aid of EDS. The result obtained from the analysis indicates that the white ash specimen consists of higher percentage of Si (49.2%) and O (49.5%). This analysis was then confirmed by the observation of the specimen taken from the part of the burnt bushing. Later observation suggests that the compound silicon dioxide (SiO_2) belongs to the silicone-rubber stress cone of the high voltage bushing [10].

Specimen II-Bushing Housing Ashes: Fig. 4 shows different spectrums, obtained from the EDS analysis by selecting random locations within the scanned *Bushing Housing Ash* specimen. Fig. 5 illustrates different identified elements and their relative proportions in percent,

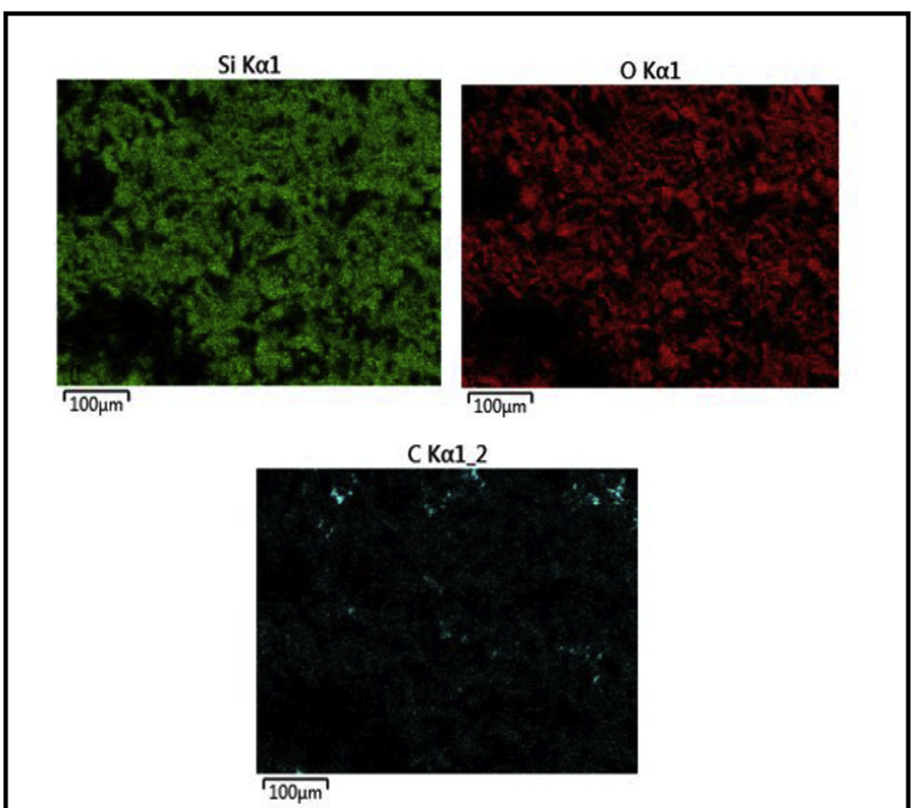

Fig. 2. EDS mapping image of white ash specimen constitutes of three main elements Si, O and C.