AN OPTICAL SENSOR FOR MONITORING SF_6 DISSOCIATION IN A CORONA DISCHARGE

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§1. Introduction

Sulphur hexafluoride (SF_6) is a chemically inert gas (Schumb, 1947) and has high dielectric strength, 3 times greater than air (Morrison and Robins, 1994). In high voltage systems, it is used both as a dielectric and an arc-quenching medium. An electrical breakdown event such as a partial discharge (corona) or arc will dissociate SF_6 into sulphur fluorides, sulphur and fluorine. In a contaminant-free environment, the dissociation products recombine back to SF_6 after extinction of the electrical discharge. Otherwise, some of the products will react with contaminants such as water vapour and oxygen, and with the metal surfaces and electrodes of the discharge chamber, to produce by-products including gaseous sulphur oxyfluorides and solid by-products (Van Brunt, 1985; Griffin et al, 1990 and Vukovic, 1997). As a consequence, a reduction in SF_6 concentration takes place, and the insulating efficiency of the system is degraded. If the SF_6 is not renewed, failure of the high voltage system is likely to eventually occur. One method of monitoring a system is to look for the presence of partial discharges, using techniques such as ultrasonic wave detection (Auckland et al, 1996) or fluorescent plastic fibre (Kurosawa et al., 1997). More directly, the integrity of the SF_6 may be examined using techniques such as mass spectrometry, gas chromatography-mass spectrometry and Fourier Transform Infra-Red Spectroscopy. Such techniques, however, are bulky and require gas samples to be extracted, and so they are unsuited to field use. Since SF_6 insulating systems involve high voltages and a high level of electromagnetic interference, direct in-situ optical monitoring appears to provide the best approach. This paper describes the development of such an optical sensing technique, specifically for continuous monitoring of SF_6 degradation in partial or corona discharges.

§2. Principle of the Sensor

The dominant dissociation product of the SF_6 discharge is atomic fluorine and it is also the most reactive product (Cotton and Wilkinson, 1988). Because fluorine reacts rapidly with the immediate surrounding surfaces, it never appears on the mass spectra of the discharge gas samples. This reactivity is utilised in our optical fibre sensor, where etching of a glass fibre surface by fluorine modifies the transmission characteristics of the fibre. Etching causes an increase in light scattering from the fibre and hence a reduction in transmission. By monitoring the transmitted signal, it is possible to obtain information on fluorine production and hence SF_6 dissociation.

§3. Experiment

The corona chamber of volume 2.9 litres was manufactured from a single cylinder of aluminum alloy type 6351. Discharges were produced between point and plane stainless steel electrodes placed 1.5 cm apart. Four 10-cm diameter ports allowed windows and probes to be attached. In this work, two of the ports were used, one with a glass window and one supporting the optical fibre sensor shown in figure 1. The other ports were sealed

with aluminium plates. Light transmitted through the fibre was monitored using a UDT photodiode PIN-6DPI. Four different light sources were used; a white light source, a Uniphase He-Ne laser with wavelength 633 nm, a Ledtronics super-bright blue LED with central wavelength 450 nm and a Toshiba ultrahigh bright red LED with central wavelength 644 nm. An AEI MS10 magnetic sector mass spectrometer was used to examine gas samples taken from the discharge volume. The U-shaped sensor was a 1mm-diameter glass fibre made of Corning 7740 borosilicate glass. It is important to choose a glass type for which the etching process produces a high degree of light scattering. Several types of glass were examined before choosing this particular glass, and the reasons for the choice are discussed in §5.

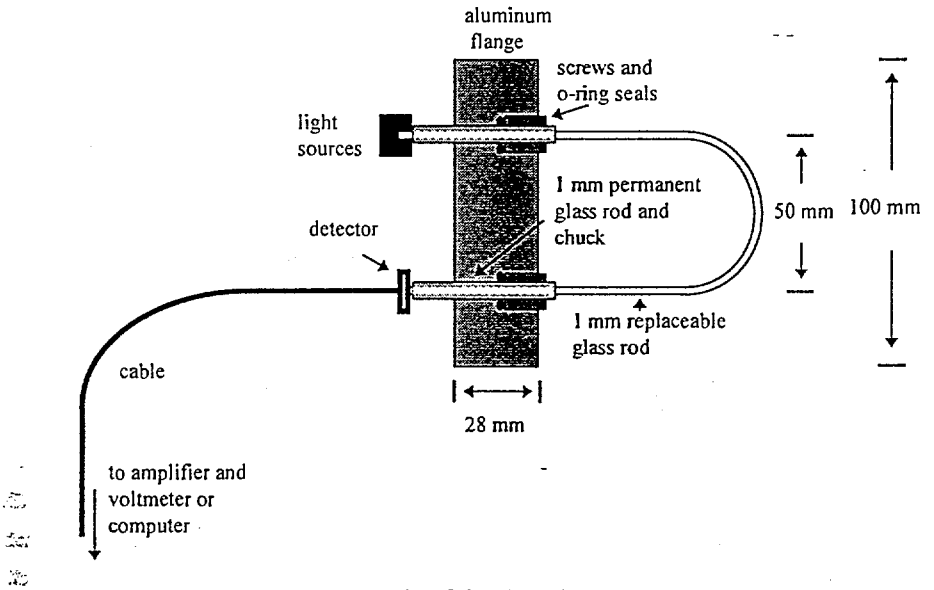

Figure 1. Structure of the optical fibre sensor for SF_6 dissociation

Prior to each experiment, the corona chamber was evacuated to 10^{-5} Torr and then filled with SF_6 gas to a pressure of 100 kPa. The corona discharge current was continuously monitored and maintained at 75 μA. At one or two-hourly intervals, the light intensity at the optical sensor output was measured and a discharge gas sample was examined using the mass spectrometer.

§4. Experimental results

Figure 2 shows curves of SF_6 and discharge-product concentration as functions of the discharge time through the corona, as obtained from the mass spectrometric data. Three major gaseous discharge products, SiF_4, SOF_2 and SO_2F_2 were detected. A small amount of HF was also detected at later times. The oxyfluorides indicate the presence of some water vapour in the original SF_6 gas, while the SiF_4 is produced by etching of the glass chamber windows and optical fibre. Possible reactions producing SiF_4 are:

$$2SF_4 + SiO_2 \longrightarrow SiF_4 + 2SOF_2 \quad (1)$$

$$SF_4 + SiO_2 \longrightarrow SiF_4 + SO_2 \quad (2)$$

$$2SOF_2 + SiO_2 \longrightarrow SiF_4 + 2SO_2 \quad (3)$$

$$4HF + SiO_2 \longrightarrow SiF_4 + 2H_2O \quad (4)$$

$$4F + SiO_2 \longrightarrow SiF_4 + O_2 \quad (5)$$

Reaction (5) has the fastest rate (Cotton and Wilkinson, 1988), and is likely to be the main contributor to SiF_4 production.

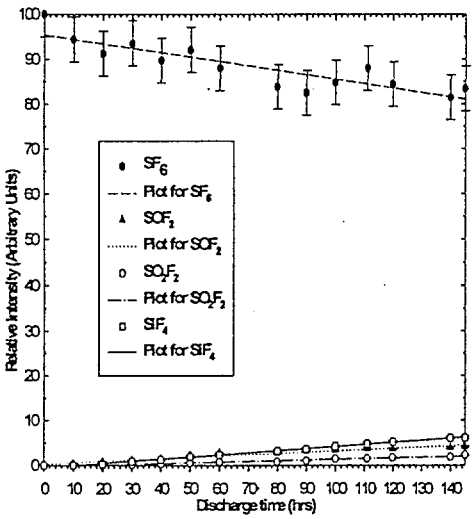

Figure 2. Concentration curves for SF_6, SOF_2, SO_2F_2 and SiF_4 in a 100 kPa, 75μ a corona discharge.

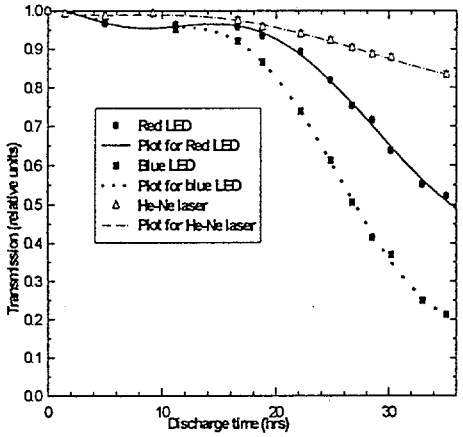

Figure 3. % transmission through the sensor as a function of discharge time.

Figure 3 shows transmission through the U-shaped fibre as a function of discharge time for three different light sources. The bulk of the light transmitted through the sensor is incident on the boundary of the fibre at angles greater than the critical angle for total internal reflection, and so reaches the detector. During the discharge, however, as a result of etching, the surface of the fibre becomes increasingly uneven so that more and more light is scattered out of the fibre. The degree of scattering therefore provides a measure of the production of etching gas, most probably fluorine, and hence the rate of dissociation of SF_6. The use of a white-light source and monochromator showed that, as expected, the scattering loss increases with decreasing wavelength, and this is seen in figure 3 with the faster fall in transmission for the blue LED.

§5. Discussion

Several different types of glass were examined in order to determine which was the best choice for the sensing fibre. For example, it was found that a pure silica fibre was unsuitable because the etching process produced such an even degree of etching over the whole fibre surface that little or no scattering of light out of the fibre took place, even after a discharge exposure of 50 hours. This conclusion was supported by electron- microscope analysis of the exposed fibre, which showed a very uniform etching pattern. On the other hand, an electron-microscope analysis of Corning 7740 borosilicate glass exposed to a 50-hour discharge revealed very uneven etching. Indeed, the electron microscope pictures suggest that etching is due primarily to the reaction between fluorine and silica (SiO_2), with other non-silica species being relatively unaffected by the discharge. As seen in Table 1, the Corning glass contains substantial amounts of B_2O_3 and Na_2O, and it is regions of these unetched species that essentially provide a distribution of scattering centres at the fibre surface. The non-silica species essentially mask the silica surface in an irregular manner during the etching process.

Chemical	SiO_2	Na_2O	B_2O_3	CaO	Al_2O_3	MgO	K_2O	Fe_2O_3	Cl
Percentage	80.5	3.8	12.9	0.10	2.2	0.05	0.4	0.04	0.10

Table 1. Chemical content of Corning 7740 glass (Hart, 1992).

The sensor shows promise as a monitor for SF_6 degradation in high-voltage systems. It can be assembled with an LED as light source, a pin photodiode as photodetector and a small

U-shaped glass rod. The sensor is relatively cheap, is easy to use, can be readily retrofitted; and it is suitable for continuous monitoring.

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