Advanced Method of Surface Potential Measurement with a Field Mill Probe

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Abstract

This paper deals with the introduction of a miniature fluxmeter or so-called field mill system for determining surface potential of insulators or metallic surfaces. The surface potential probe is specially designed to measure surface potential of charged real life cylindrical GIS spacers with and without ribs. A multiple sensing electrode allows measurements in two dimensions.

Introduction

Today SF_6 and SF_6/N_2 gas insulated switchgear (GIS) and transmission lines (GIL) are the standard technique if high voltage apparatus with small size and high reliability is required.

To provide high reliability of the complete insulation system "GIS" the weakest component of the insulation has to be considered with special care. The gas/insulator interface is one of the most critical areas in this insulation system.

One of the phenomena which is responsible for initiating flashover at spacers is charge accumulation on very high insulating spacers [1, 2]. Charge accumulation on spacers in GIS for a.c. voltage may occur due to corona at free or fixed particles floating in the inner of the GIS. These particles come into the GIS during the erection procedure in the factory or on site. Deenergisation of sections of the GIS may also cause so-called trapped charges.

The electric field of the accumulated charges is superimposed with the field applied by external means, and this may lead to such a severe distortion of the original field, that flashover may occur. Aim of our future work will be the determination of accumulated charges on real live spacers, electrically stressed in a gas encapsulated and insulated test vessel. To detect the field distribution the spacer has to be scanned with a high resolution field probe. Thereby fast rotations of the spacer for means of field measurement have to be avoided because of the possibility of charge recombination with the insulating gas. Especially for busbar spacers with ribs, as shown in figure 1, which are commonly used in single phase substations, charges may accumulate on the top and bottom sides of the spacers ribs, due to the relatively low tangential field strength. The trapping mechanism has to be understood and for this measurement of surface charge into both directions, normal and tangential to the applied electrical field has to be performed. The shape of the spacer has to be evaluated for optimisation of the insulation performance, using the information gained by charge measurement.

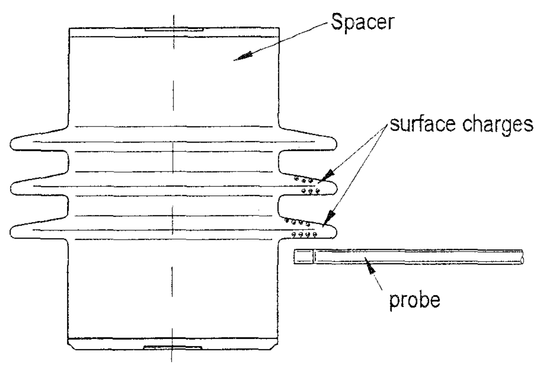

Figure 1: Surface charges on a spacer with ribs

To gain the above mentioned information, a field mill probe, optimised and specially designed for this application, was constructed.

Principle of field mill operation

Operation of the field mill system is based on the change of the capacitance of a sensitive plate to the investigated object. The change of the capacitance is realised by either a periodically change of the distance to the sample, the so-called vibrating electrostatic modulator [2] or periodically screening of the sensitive plate or electrodes [3, 4, 5], and for

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this changing periodically the exposed area of the field sensitive electrodes, the field mill system.
In most cases an electrostatic field has to be determined. Assuming a uniform field, the chopped flux generates an alternating measurement current i_m according to the following equation (1):

$$i_m = \frac{d}{dt}(C \cdot U) = E \cdot d \cdot \frac{d}{dt}(C) = \varepsilon_0 \varepsilon_r E \cdot \frac{d}{dt}(A(t)) \quad (1)$$

where d is the distance between the investigated sample and the probe and E is the applied field, at the field sensitive electrodes. The time dependent area exposure A(t) of the field sensitive electrode can be approximated with equation 2:

$$A(t) \cong \frac{A}{2}\left(1 + \cos(n\omega t)\right) \quad (2)$$

where n depends on the number of screenings per turn of the mechanical field mill construction.

If the potential of the probe is driven by a high voltage source, the induced measurement current i_m may be regulated to zero. Then the potentials of the investigated surface and of the probe are the same, and the voltage distribution of the scanned surface can be determined.

Advanced measuring set-up

If measurements of charge accumulation on cylindrical spacers with ribs have to be performed, the problem arises, how to measure into two dimensions with only one probe. This problem has been solved by combining a plane [4] and a coaxial fluxmeter [5] in one mechanically coupled system.

The construction of the cylindrical shaped field mill system can be seen in figure 2. The two sensing electrodes have a rectangular shape of 1x1 mm. They are connected by an sensing collector. A pin, coming from the sensing collector , decouples the measured signal to a coaxial wire, which feeds the measuring amplifier.

The described system is embedded in resin to prevent contact to the surrounding shielding. Because the sensing system is non rotating, it is called stator. It is possible to integrate up to four field sensitive electrodes in the stator, if required. A different stator may be attached to the probe and for this the stator was constructed pluggable. For a surface potential

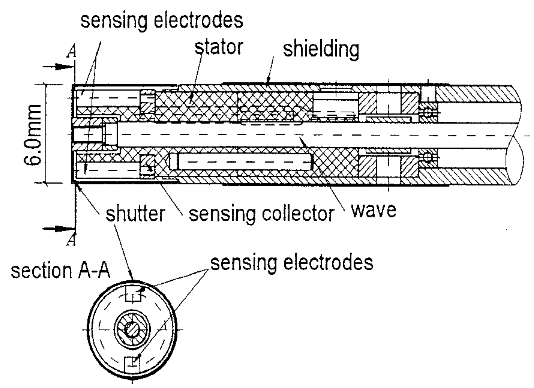

Figure 2: Section of the sensing electrode system

scan on one level two electrodes are sufficient, in order to provide a resolution of 1 mm in square.
The screening of the field sensitive electrodes is provided by a shutter, which is directly connected to the driving shaft. The shaft is running in ball bearings, driven by a miniature motor and connected with the shielding through carbon brushes. To provide a high sensitivity and on the other hand a satisfying shielding, the shutter runs with only 1/10 mm clearance to the stator. Figure 3 shows a schematic of the used shutter.

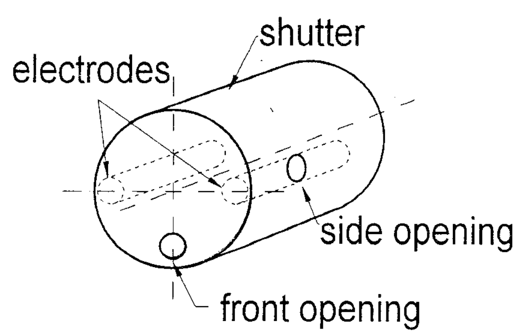

Figure 3: Schematic of the shutter

On the front and the side of the shutter field feedtrough holes were placed, shifted by 90 degree. If one electrode is (dynamically) unscreened and applied to an positive DC field, a positive measurement current i_m will flow towards the shielding, if both, electrode and shielding are connected with a measuring impedance. Again screening the same electrode a current of reversal polarity will flow, having the same amplitude as the first one. In other terms, one "field" sample of a field sensitive electrode will generate two current pulses of the same amplitude. Therefore, one turn of the shutter (figure 3) over the stator will generate eight current peaks, which have to be detected.

Signal processing

The correct processing of the generated signals is of great importance. If measurements with given shutter and stator configuration (figure 3) are provided, they have to be done phase resolved. Four different electrode signals have to be differentiated: The actual field at the front of the left electrode, then following, the field at the side of the left electrode and the same for the right electrode (figure 4b). Figure 4a shows a schematic flow chart of the signal processing. The measured current peaks are first amplified with an low bias operational amplifier. Then every current peak is integrated, so that statistical deviation due to noise has small influence on the result. Important is the fast and bipolar discharging of the integration capacitor. The reset impulses are generated by a phase locked loop circuit (PLL), which is locked onto the frequency of the mechanical shaft rotation. The number of revolutions is detected optically. By switching an eightfold divisor circuit into the feedback of the PLL, from every turn of the wave eight reset impulses are generated. The correct phase reference between reset impulses and the measurement current i_m is adjusted by varying delay, before switching.

Practical considerations

If measurements of surface potential have to be performed under severe conditions, as intended here by measuring surface potential of spacers in an SF_6 and SF_6/N_2 gas insulated test vessel, especially the field sensitive parts of the field mill system have to be designed with great care. Shutter and field sensitive electrodes have to be coated with a gold layer to prevent oxidation of the electrode material. An insulating oxide layer may decrease the sensitivity of the field mill system, due to possible charging of the insulating layer.

All parts which are of importance for the shielding of the sensitive electrodes as shutter and connected driving shaft have to be connected properly to the shielding of the probe (figure 2).

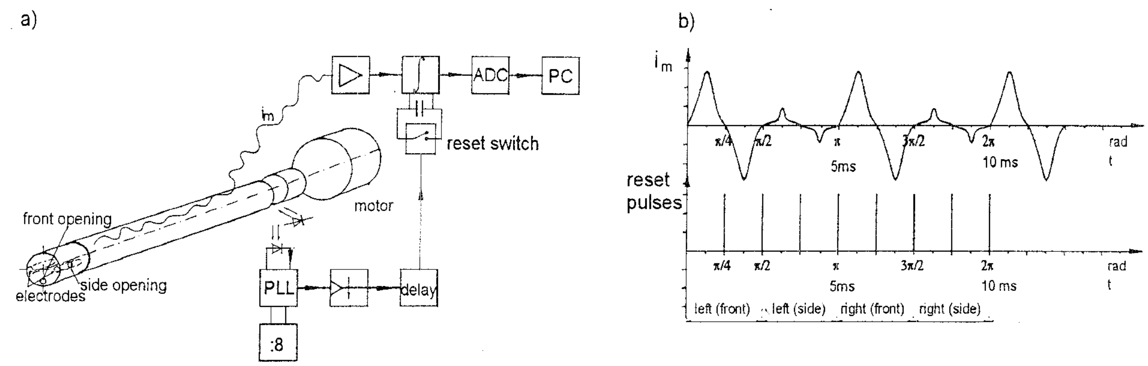

Figure 4: a) Schematic of the signal processing b) Example of phase reference between reset impulses and i_m for one turn of the shutter at 6000 rpm

A big advantage of the field mill system is, that chopping the flux, creates alternating currents, which can easily be amplified. Before starting a measurement, no zero setting, in order to calibrate the instrument, is required.

Problems due to the high amplification that is needed for this miniaturised field mill system, shall be considered in the following. Assuming surface charges of several 10 $\mu C/m^2$ on a spacer under DC stress [6] and a minimum resolution of $1\ \mu C/m^2 = 1\ pC/mm^2$ for the field mill system, the electrical field strength (simplified for an homogeneous field) seen by the sensitive electrodes is according to equation 3:

$$E = \frac{\sigma}{\varepsilon_0} \cong 113 \frac{kV}{m} = 113 \frac{V}{mm} \qquad (3)$$

Applying this field to the field mill electrodes, a peak current of equation 4 using equation (1) and (2):

$$\hat{i}_m = 2\varepsilon_0 E n \omega A \approx 1 \text{ nA} \quad (4)$$

is induced into the apparatus, with $A = 1$ mm^2 and $\omega = 2\pi f$ assuming 6000 rpm corresponding with $f = 100$ Hz of the driving motor and $n = 4$ because four screenings per turn are provided with the used shutter (figure 4b). As can be seen, sensitivity increases by revolution rate ω and exposed field sensitive area A. Due to specification of the ball bearings the revolution rate of the shaft is limited to 6000 rpm. The area A is given by the resolution and the physical dimension of the probe head (miniaturisation).

To reach a sufficient output of the amplifier this will require an amplification of about $G = 100\text{-}1000 \times 10^6$. Using a current-voltage converter, a feedback resistor of $R = 500$ MΩ is necessary. To keep noise small and to limit the value of the parasitic parallel capacity of the feedback resistor, shielding of the feedback resistor is required. Despite shielding the feedback resistor, the remaining parasitic parallel capacitor still has a measured value of about $C_p = 0.5$ pF. This RC combination mainly limits the cut off frequency of the amplifier to equation 5:

$$f_c = \frac{1}{2\pi R C_p} \approx 636 \text{ Hz} \quad (5)$$

Reminding that the frequency of the used shutter-stator (figure 3) configuration is 4 times higher than the rotating frequency of the motor (figure 4b, one mechanically turn $2\pi = 10$ms) it can be seen, that the applied frequency of 400 Hz corresponding with a period of 2,5 ms is near the cutoff frequency. This shows the that the field mill is working near the theoretical limits of sensitivity which is due to the miniaturisation.

Future work

To interpret the performed measurements correctly, two other important aspects have to be considered. First of all the measurements will not be performed in an uniform field. For this a field correction factor or λ-function [7, 8] for this probe will have to be introduced. Second, the feedthrough of the electrical field of a sensitive electrode to a neighbourhooded sensitive electrode has to be considered analytically.

Conclusions

An improved field mill system for measurement of surface potential of charged insulators is introduced. New features are the miniaturisation of the field sensitive probe head and the ability of the probe to measure surface potential into two dimensions of a level (x and y axis for example) without changing the probe. The principle of operation of the signal processing electronics is explained. Referring to practical problems, and paying attention to the applied frequencies in the field mill system, the limitations of the miniaturised field mill system have been pointed out.

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