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C_{60} as flow electrification inhibitor in mineral insulating oil

P. Aksamit, D. Zmarzły*

Faculty of Electrical Engineering, Automatic Control and Computer Science, Opole University of Technology, ul. Prószkowska 76, 45-758 Opole, Poland

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ABSTRACT

The paper presents the concept of using C_{60} fullerenes as streaming electrification process inhibitor in mineral insulating oil. For the research, 20 samples of oil were prepared; one pure and 19 containing from 1 mg/l to 512 mg/l of C_{60}.

The electrification current was measured using a wireless electrometer spinning disk system for rotational speeds from 0 rpm to 400 rpm. The research revealed the C_{60} ability to significantly reduce the constant component of streaming electrification current in mineral transformer oil. The C_{60} additive causes also the significant change in flow electrification mechanism as indicated by current versus flow velocity relations.

1. Introduction

During last decades, dozens of transformer failures connected with streaming electrification were documented around the world [1–7].

As the demand for electric power in the world grows, it necessitates an increase of power and rated voltage of transformer units. To dissipate the heat generated in high-voltage transformers, a forced flow of cooling oil is used. When insulating oil flows through transformer windings, the static electricity is generated in the vicinity of the solid insulation surface. The high electric charge may lead to surface discharges. In effect, the solid insulation degrades gradually, which can eventually cause a full discharge and transformer failure.

To reduce the flow electrification, the oil flow velocity in most power transformers does not exceed 1 m/s. However, lower oil flow requires higher capacity of the transformer units to achieve sufficient heat dissipation conditions.

Suppression of flow electrification phenomena would allow increasing the flow of the cooling oil, thus improving the cooling conditions and reducing capacities of transformer units, without bringing a threat of transformers failures due to static electrification. As each high-voltage transformer failure brings significant economic losses and is dangerous for the entire power system integrity, intensive research works on flow electrification phenomena have been conducted in many research centers in the world [8–15].

Up to this date, the most broadly researched insulation oil additive, used for flow electrification reduction and as a copper surface passivator is 1,2,3-benzotriazole (BTA) [16–19]. For several years, BTA was used as inhibitor in transformers in Japan and Australia [16,19]. There are however some uncertainties about long-term ageing and a negative impact of BTA on breakdown voltage of insulation oil [3, 20–24]. The ambiguous results obtained by different researchers were probably the reason why BTA has not became a universally adopted solution to flow electrification problem.

The authors examine the proposition of using C_{60} fullerene as an inhibitor for flow electrification in transformer oil. During the research, fresh, mineral insulation oil was doped with different amounts of C_{60} fullerenes and examined for flow electrification.

2. Preparation of oil samples

For the purpose of the research, 20 samples of fresh mineral insulation oil were prepared. One sample contained the pure oil. The other 19 samples were doped with different amounts of C_{60} fullerenes (Table 1).

Each sample was of 1 l capacity. To prepare the C_{60} doped samples, specific amount of C_{60} fullerenes was weighted using the analytical balance and pour into 1 l of oil. The C_{60} doping was based

* Corresponding author. Tel.: +48 77 400 0571; fax: +48 77 400 0573.
E-mail address: dariusz@zmarzly.com (D. Zmarzły).

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Table 1
Concentration of C_{60} fullerenes in insulation oil samples.

Probe number	C_{60} concentration (mg/l)	C_{60} mass share (ppm)
1	0	0.0
2	1	1.1
3	2	2.3
4	4	4.5
5	8	9.0
6	10	11.3
7	12	13.6
8	16	18.1
9	20	22.6
10	24	27.1
11	32	36.2
12	48	54.2
13	64	72.3
14	80	90.4
15	96	108.5
16	128	144.6
17	192	216.9
18	256	289.3
19	384	433.9
20	512	578.5

on natural solubility of fullerenes in mineral oil. The oil was kept at room temperature of about 22 °C. Each sample was stirred once a day with a glass stirrer to equalize the C_{60} concentration over the liquid volume.

The highest amount of fullerenes of 512 mg/l dissolved completely in 16 days.

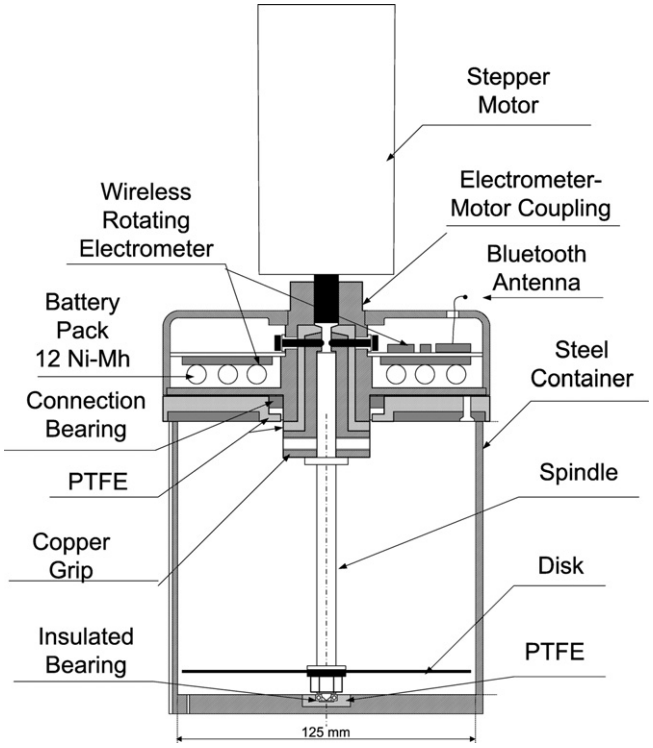

Fig. 1. Mechanical structure of wireless rotating electrometer.

3. Measurement setup

Each sample was examined against flow electrification using the wireless rotating electrometer developed at Opole University of Technology [9,10]. Mechanical structure of the setup is presented in Fig. 1.

The electrification current flowing between the container and the disk, throughout the liquid is measured using electrometer assembled on the spindle above the steel disk. A fixed, steel container with outer diameter of 130 mm and 135 mm of height (volume of 1.6 l) is closed with cap that encloses the electrometer. The cap has isolated bearing which makes the rotation of

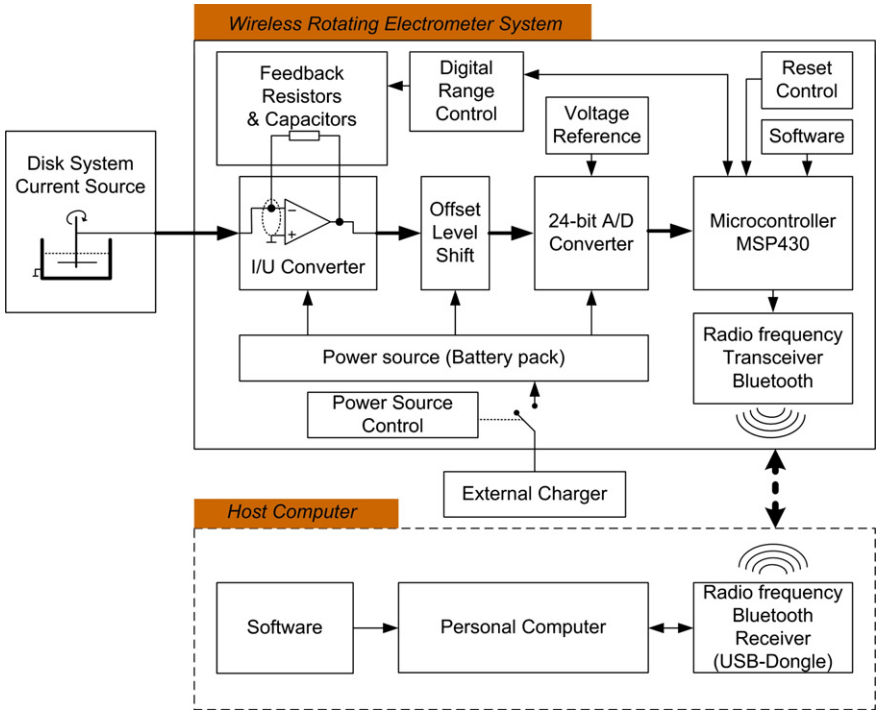

Fig. 2. Block diagram of the measurement system.