New thermo-magnetic material wire used for self-protection high voltage line overhead conductors against frost/ice deposits

A. IORGA, M. CODESCU*, L. PALII
National Institute for Research and Development in Electrical Engineering ICPE-CA
313 Splaiul Unirii, Bucharest-3, code 030138, Romania

The accumulation of ice/frost on overhead high voltage line (HVL) conductors may cause various problems such as broking and voltage interruptions. In this work is presented a new method to melt the ice/frost deposits from the overhead conductors, method that use the heat generated by a magnetic material wire. This method has been developed and tested on an experimental model. However, by the method using the magnetic wire, the conductor can gain sufficient heat to melt the deposits of frost/ice due to the multifunctional material used, which is characterised by low Curie temperature.

(Received October 26, 2012; accepted February 20, 2013)

Keywords: Low Curie temperature, Magnetic wires, De-icing method

1. Introduction

The accumulation of frost/ice on overhead high voltage transmission lines increases the conductor load and it may result damages to transmission and/or conductor galloping oscillation. In literature are recorded multiple events of breaking of overhead conductors, particularly in areas with cold climate [1-4]. For this reason, our research is based on thermo-magnetic properties of Fe-Ni-Cr multifunctional alloy in order to protect the overhead lines against frost/ice deposits [5-7].

To solve these problems was manufactured and optimized the Cr-Ni-Fe ternary alloy and design the new conductor with self protection to frost/ice. It has been developed a method, that use the heat generated by the alternative magnetic field of a magnetic material wire made from Cr-Ni-Fe alloy. The heat in the wire is due to the hysteresis loss and eddy current loss.

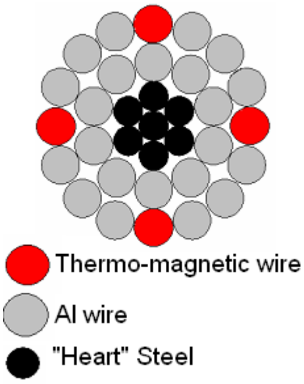
The commutation YES / No to extra heat, that ensure the non-deposition of frost/ice on the overhead conductor, is achieved by pre-stable modification of thermo-sensitive properties of the multifunctional alloy wire type, according to ambient temperature. This extra heat decreased gradually with increasing of the ambient temperature. For positive temperatures, there is no supplementary thermal/caloric intake.

2. Experiments

Innovative quality of this overhead conductor for electricity transport, lies in the fact that operate with self-protection, permanent, self-adjusting, without additional energy consumption and is the same shape, type of construction and operating characteristics as the standard currently conductors used for this purpose in the electric overhead transmission networks.

The multifunctional alloy is inserted in the standard conductor: aluminium conductor steel reinforced (ACSR) [8], as wires with the same diameter as the aluminium wires from the exterior layer of the conductor, replacing a preset number of wires from the standard construction of conductor. The heat in a magnetic material is due to the hysteresis loss and eddy current loss. Based on recent reported works, it was selected the Fe-Ni alloy as a magnetic material [6]. In order to optimize the Fe-Ni alloy behaviour at temperature, the Ni amount in the selected alloy was increased, being well-known that Ni is the effective element for increasing of heat. Also, was added Cr to the Fe-Ni alloy in order to obtain lower Curie temperatures. In order to put the new material into practical use was manufactured and tested the new conductor, realised by insertion of Fe-Ni-Cr multifunctional alloy wires. Previously insertion was calculated the energy / electro-thermal balance, involved in the operating process [9] and sized the Fe-Cr-Ni wires from the point of view of shape, section, was designed the new cable with the functional material added to the classical conductor wires, positioned in the section of former aerial conductor for energy and analysed the functionality of the entire ensemble at transient regime of temperatures.

The new magnetic wire must be inserted in conductor easily. Therefore, was decided that the basic method would be to make a wire with the same diameter as the wire from the out layer of the conductor in order to not change the manufacture and exploitation technology of it. In the present research, was studied and tested a configuration with 4 wires insertion on standard conductor used in transmission lines (s. Fig. 1). The diameter of the conductor is 24.9 mm and the diameter of each wire is 3.2 mm.



a) Cross-sectional construction

b) Experimental model

Fig. 1. Conductor with 4 wires insertions made from Fe-Ni-Cr alloy.

Basic approach

Main magnetic materials, which are ferromagnetic at ordinary temperature, are Fe, Ni and Co. Co was excluded because of higher Curie temperature (1124^{o}C) than Fe (770^{o}C) and Ni (354^{o}C), and also it's expensive. For this reason and based on other researches [6], Fe-Ni alloy was selected. Fe and Ni have higher Curie temperature than Fe-Ni alloy. The Curie temperature of Fe-Ni alloys shows a minimum value, approximately 300^{o}C, a content of Ni around 35 wt. %. It has been observed that Cr also is an element which decreases the Curie temperature [6]. Thus, Fe-Ni-Cr alloy with a Ni amount around 35 wt. % has been used as magnetic material for this study.

Heat value is expected to rise by increasing Ni content, since the maximum magnetic flux density increase with Ni content. Cr is added to prevent a rise in Curie temperature. Were realized 4 types of Fe-Ni-Cr alloy (s. Table 1, samples PA, PB, PC, PD), varying Fe, Ni and Cr content. The Fe-Ni-Cr alloy was realised starting from pure elements: Cr, electrolytic Ni and technical iron (Armco type). The melting was done in furnace with induction heating, under argon atmosphere. After casting, the alloys were annealed for stress relief and chemical homogeneity in the composition; the thermal conditions were 3 hours at 700 ^{o}C and cooling with furnace. The annealing was carried out in argon, at atmospheric pressure.

Table 1. Chemical composition of the multifunctional wires.

Sample code	Chemical composition of alloys (wt. %)
PA	Cr5-Ni33-Fe62
PB	Cr12-Ni35-Fe53
PC	Cr10-Ni35-Fe55
PD	Cr11-Ni33-Fe56

To obtain wires, the alloys were processed by hot (forging) and cold (rolling and drawing) forming processes. Wires made by drawing have 3.2 mm in final diameter, the wire drawing speed being ~ 0.8 m/s (s. Fig. 2).

Fig. 2. Magnetic material wire made by Cr-Ni-Fe alloy.

3. Measurements and results

Metallographic and XRD investigation reveals that all the investigated alloys are single phase in the range of positive temperatures. This substitutional solid phase has the crystalline structure type γ / FCC, with cell parameter a $\approx$ 3.570 Å. The structure of these alloys confirms the possibility of alloys technological processing by hot and cold plastic deformation, in good conditions.

The next step was the measuring of the Curie temperature for all 4 samples. The Curie temperature defines the reversible transition temperature from the ferromagnetic to paramagnetic state. The thermo-magnetic alloy, newly created for this purpose, was characterized through thermo-sensitive magnetic, predetermined and reversible properties, without thermal hysteresis and also without transformations of the crystalline structure.

Measurements were performed using MPMS (Magnetically Properties Measurement System) SQUID facility, in a magnetic field of 100 Oe. The temperature range for measurements was - 40°C to +130°C.

Fig. 3 presents the variation of magnetization with temperature for Cr10-Ni35-Fe55 alloy (PC sample from Table 2). From the M = f(T) variation can be determinate the Curie temperature T_C, specific for each studied alloy.

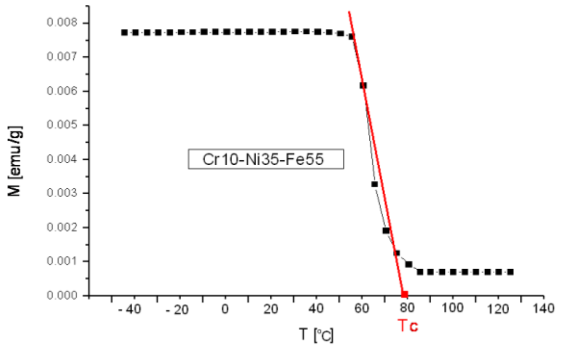


Fig. 3. Variation of magnetization with temperature for Cr10-Ni35-Fe55 alloy.

Table 2 presents the results of the measurements, the lowest Curie temperature being obtained for the Cr12-Ni35-Fe52 alloy (s. PB sample from Table 2).

Table 2. Measured values of Curie temperature T_C.

Sample code	Chemical composition (wt. %)	T_C (°C)
PA	Cr5-Ni33-Fe62	120
PB	Cr12-Ni35-Fe53	10
PC	Cr10-Ni35-Fe55	78
PD	Cr11-Ni33-Fe56	55

Frost is deposited on the conductor when the temperature reaches - 3°C; to achieve a stable thermal process, has been chosen for the conductor a magnetic material with T_C higher than 0°C, in order to have a relatively large amount of magnetic flux density at 0°C, but not more than 30°C – 50°C, in order to avoid overheating of the cable when the ambient temperature is positive. So, the selected alloy in order to be used for the inserted multifunctional wire was Cr12-Ni35-Fe52 alloy.

From the amount of heat lost by the system and the heat brought by one wire from the new multifunctional alloy, replacing the aluminium wires, will result the number of necessary wires that have to be replaced in the outer layer of the standard ACSR conductor. For practical reasons and based on calculations made, was considered that the insertion with 4 wires replaced is the most advantageous and meets the objective proposed.

Tests in climate chamber

The experimental model (EM) of the conductor (Fig. 1.b), on which was performed the tests, was made by replacing 4 aluminium wires with 4 multifunctional wires from Cr-Ni-Fe alloy in the ACSR standard conductor. The conductor on which was performed the laboratory tests had a length of 1500 mm and test were done at 320 A/50 Hz, representing 50% of nominal capacity.

For functional testing of the experimental model was used a complex montage, shown schematically in Fig. 4.

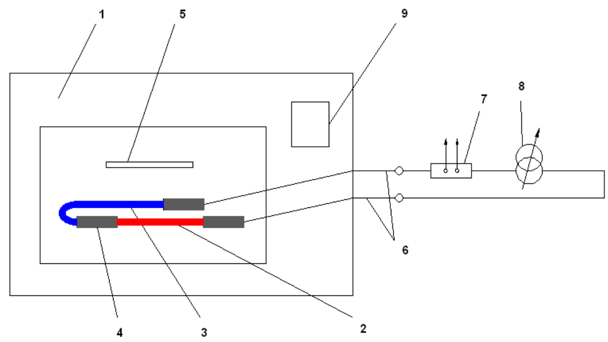


Fig. 4. Scheme of the montage for the ice behaviour tests of EM in climatic chamber. 1-climatic chamber; 2-conductor with insertion of Cr-Ni-Fe multifunctional alloy; 3-standard conductor; 4-supply connections; 5-standard conductor out of function; 6-connectors; 7–shunt: 1000 A / 0.25 V; 8-power supply 0-500 A; 9-control panel.

Test facility is composed primarily of a climatic chamber with the possibility of adjusting temperature in the range of - 30°C … + 50°C, 100 % humidity and wind speed up to 16 m/s. Construction type camera is compact, with tight connection and having the possibility of crossing plate measuring circuits and power supply. In the climatic chamber, beside the self-protection conductor, have been introduced also a control conductor (not connected to the power supply) and one standard conductor connected in series with the conductor with self-protection to deposition of frost/ice.

Climatic chamber tests on the self-protection conductor to the deposition of frost/ice reveals that, at stabilized climate chamber temperature of - 15°C, the standard conductor has a temperature of - 4.2°C (s. S2 point in Fig. 5) and for the new self-protective conductor, with insertion of Cr12-Ni35-Fe52 wires, temperature is + 0.3°C (s. S1 point in Fig. 5). The blank test conductor has almost the same temperature as the temperature in the climatic chamber, namely around - 14.8°C (s. S3 point in Fig. 5).

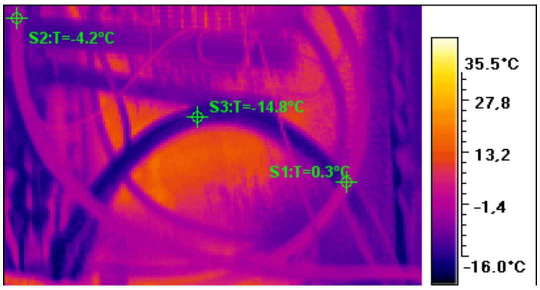


Fig. 5. Thermogram image during the functional tests performing, on the studied conductors, after temperature stabilization in the climatic chamber.

Conductor temperature difference between standard and self-protective conductor to the deposition of frost/ice power was 4.5 °C. Also on the non-connected conductor (blank test) was observed a thick layer of frost.

4. Conclusions

The new realised conductor ensures the self-protection at frost/ice deposits on the electric overhead transport lines, without requiring additional energy consumption, without human or automatic intervention for control and with no ecological effects on the environment. The commutation YES/NO to extra heat, which ensures the un-deposition of frost/ice on the overhead conductor, is achieved by pre-stable and reversible modification of thermo-sensitive properties of the Cr-Ni-Fe multifunctional alloy wires.

Based on positive results obtained, the studied alloys can be used in future researches regarding the manufacturing of the electric overhead conductors with self-protection to deposits of frost/ice.

It should be noted that due to specific properties of new functional materials at positive temperatures, it behaves like an ordinary electrical conductor. These results obtained during the experimental work, make the subject of OSIM patent application no. A– 00690/2010.

Acknowledgements

This work has realized under the project No. PNII 21-012/2007. The technical and scientific results, presented in this paper, are the subject of the Patent Request No. 00690/02.08.2010 (RO 125940 – AO).

References

[1] Qiang Xie, Ruiyuan Zhu, in IEEE power & energy magazine, **9**, 28 (2011).
[2] L. M. Goia, Romanian Experience in Icing Management, Proc. of World Energy Council – Regional Energy Forum - FOREN 2008, Neptun (2008), pp. 1-7.
[3] Pierre Van Dyke, D. Havard, A. Laneville, Springer Science + Business Media (2008), pp. 171 -175.
[4] Huang Xinbo, Liu Jiabing, Cai Wei, J. Power System Technology **32**, 23 (2008).
[5] Masoud Farzaneh, Anti-icing and De-icing Techniques for Overhead Lines, in Atmospheric Icing of Power Networks, Springer Science + Business Media (2008), pp. 229–232.
[6] Toshio Kitamura, Snow-melting Magnetic Material Wire, Fujikura Technical Review (2003), pp. 23 – 25.
[7] Shan Xia, Shu Naiqiu, Discussion on Methods of De-icing for Overhead Transmission Lines, J. High Voltage Engineering 32, (2006), pp. 25-27.
[8] *** SR CEI 61089:1996 + A1:1999, Conductors for Overhead Lines with Round Wires, Cabled in Concentric Layers.
[9] *** Modeling and Preparation of Materials Used as Self-protective Element for Frost and Ice Deposits, 2nd Progress Report on project No. PNII 12-021/2007.

*Corresponding author: mirela.codescu@icpe-ca.ro