Comparison between the measured and model-calculated temperature of the LV melting fuse

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Abstract: - Electric fuses are being used for over a century. They are an important factor for protection of electric power systems and apparatuses. This article describes a low voltage melting fuse. The authors used a numerical and real model of the fuse. The numerical model is composed of the finite elements and includes electric and temperature characteristics of a material and boundary condition values. The numerical model is formed as a 3D fuse model. The real model represents a fuse, on which were fixed thermoelements to measure the temperature in laboratory surroundings. The measurements were made under nominal current (400 A) and under half of the nominal current (200 A). This paper compares the measured temperature with the calculated, acquired by the simulation model of the fuse.

Key-Words: - low voltage, fuse link, temperature, calculation, simulation, 3D model

1 Introduction

Electric fuse is used as a protection element in all electrical engineering applications. It is a device that by melting of one or more specific planned and coherent components opens the electric circuit in which it is installed. The electric circuit is opened by current interruption at an excess of a determined value at the appropriate time [1, 2]. Main task of the fuse is to protect electrical devices, installations and people.

This paper describes a simulation model of a low voltage (LV) melting fuse in order to calculate the fuse's temperature and compare it with measured temperature of the real fuse.

1.1 Low Voltage Melting Fuse

Copper wire or fuse link burns out, when the electric current exceeds a certain threshold value. When the excess current flows through the fuse, the fuse link overheats and burns out. An electric arc is formed at this point, which evaporates the metal. It is distributed into quartz sand, where it is cooled down onto granules. The path of the arc is becoming further more constant with intense cooling during that path. Due to the high thermal capacity of quartz sand, the electric arc quickly extinguishes. The fuse is dimensioned so that the fuse link is able to withstand the desired operating current. In the event of excess of the operating current, the fuse reacts and the fuse link burns out [3].

The article deals with the LV melting fuse intended for installation in LV grid, up to 500 V. LV melting fuse (Fig.1) consists of a melting indicator, blade contacts, hollow ceramic body, fuse links, and quartz sand. The used fuse has 4 fuse links, where the three fuse links are the same width, and the fourth fuse link is narrower.

Fig.1. Low voltage melting fuse [3].

LV fuse is built from electrically conductive and non-conductive parts. Electrically conductive parts of LV fuse are fuse contacts and fuse links. Electrically non-conductive parts of LV fuse are hollow ceramic body, indicators and quartz sand. The body of fuse must be built from good electric insulation material. Usually it is made from steatite. LV fuse is connected in the electric circuit by upper and lower contact, which are attached to the ceramic case. They are interconnected with fuse links, that are spot-welded to them. Area around fuse links is filled with quartz sand, which extinguishes electric arc.

2 Measurements

The measurements were carried out in a testing laboratory at the Faculty of Electrical Engineering and Computer Science, University of Maribor.

Thermoelements (TE) were used to measure temperature, and they were placed to different locations on the outside and inside the fuse. There were 14 thermoelements. They were placed:

- On the top and the bottom of the upper blade contact (TE_1, TE_2);
- On the top and the bottom of the lower blade contact (TE_3, TE_4);
- On the upper and lower cover of the fuse (TE_5, TE_6);
- On the ceramic body (the side with the inscription, the rear and the ride side) (TE_7, TE_8, TE_9);
- On the narrower fuse link (TE_{10});
- On the second, third and fourth fuse link (TE_{11}, TE_{12}, TE_{13});
- In the quartz sand inside the fuse (TE_{14}).

A test of permanent load, i.e. joule heating the fuse was carried out. The heating was conducted firstly under the nominal current (400 A), and after that under the half of the nominal current (200 A). For the first case (I = 400 A), the fuse had all four fuse links. For the second experiment (I = 200 A), the fuse had two fuse links, where these two fuse links are the same width. Table 1 shows the measured temperature values at 400 A, and Table 2 shows the measured temperature values at 200 A.

3 Melting Fuse Simulation Model

The melting fuse model is designed as a 3D model using a mesh generator in EleFAnT 3D [4], where the whole problem area is distributed into Finite Elements (FE). Figure 2 shows a 3D model of a melting fuse with the FE mesh, where the yellow color shows the blade contacts and gray shows the ceramic body. Figure 3 shows the fuse model without ceramic body, where the fuse links can be seen (blue color).

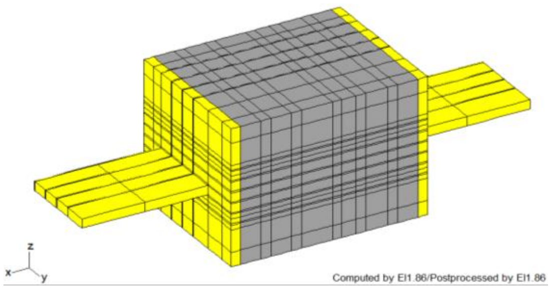

Fig.2. Melting fuse model with ceramic body.

Table 1. Measured temperature values at 400 A.

Thermoelement	Temperature [°C]
TE_1	81.32
TE_2	92.49
TE_3	81.91
TE_4	94.2
TE_5	86.48
TE_6	83.65
TE_7	76.49
TE_8	83.68
TE_9	85.95
TE_{10}	125.3
TE_{11}	134.1
TE_{12}	134.4
TE_{13}	131.2
TE_{14}	88.85

Table 2. Measured temperature values at 200 A.

Thermoelement	Temperature [°C]
TE_1	47.57
TE_2	51.74
TE_3	46.98
TE_4	51.81
TE_5	50.19
TE_6	47.91
TE_7	47.26
TE_8	49.81
TE_9	50.47
TE_{11}	75.18
TE_{13}	76.46
TE_{14}	50.59

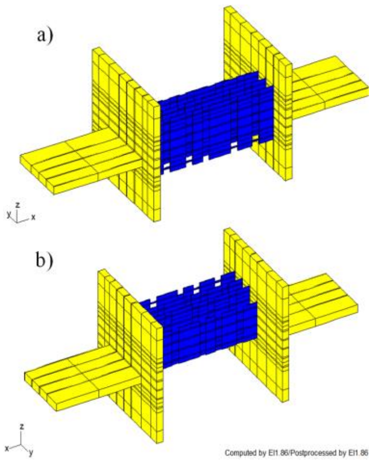

Fig.3. 3D model of a melting fuse without ceramic body: a) front view and b) back view.

The model is divided into geometric shapes that belong to respective types of material. There are five geometric shapes: upper and lower contact, ceramic body, fuse links, quartz sand and surrounding area (air). Their electric and thermal properties are show in Table 3.

Table 3. Electric and thermal properties of geometric shapes [5-7].

Geometric shape	Air	Quartz sand	Fuse links	Ceramic body	Blade contact
Electric conductivity [S/m]	1E-09	1E-09	57E+06	1E-09	11E+06
Thermal conductivity [W/m·K]	0.0257	1	401	2.5	237
Convection factor [W/m²·K]				7.5	8

The fuse model is designed as a coupled problem, since it uses electric and thermal models. The electric model calculates the current density and electric conductivity, which serve as the input data for the calculation of power losses. The values of power losses are then used as input data for the thermal model when calculating the fuse's temperature.

The numerical analysis of temperature calculation for the fuse model was conducted with the catalogue values form Table 3. The results are presented in Table 4 and 5. Table 4 compares the measured and model-calculated temperatures of the fuse under the current 400 A. Table 5 compares the measured and model-calculated temperatures of the fuse under the current 200 A. Figures 4 and 5 show an example of temperature arrangement simulation under 400 A and 200 A, respectively.

Table 4. Measured (T_{meas}) and model-calculated (T_{calc}) temperatures of the fuse under 400 A.

Thermoelement	T_{meas} [°C]	T_{calc} [°C]
TE_1	81.32	108.43
TE_2	92.49	109.18
TE_3	81.91	108.14
TE_4	94.2	108.91
TE_5	86.48	110.23
TE_6	83.65	109.93
TE_7	76.49	109.51
TE_8	83.68	109.19
TE_9	85.95	120.39
TE_{10}	125.3	117.09
TE_{11}	134.1	123.81
TE_{12}	134.4	124.11
TE_{13}	131.2	123.81
TE_{14}	88.85	118.02

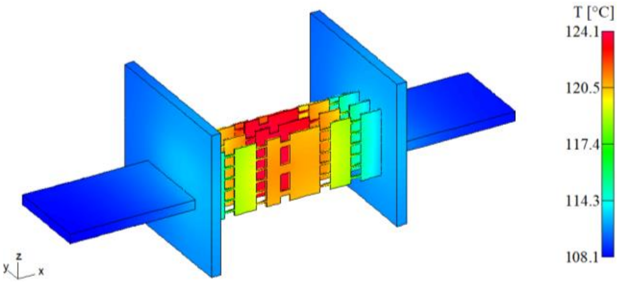

Fig.4. Temperature arrangement under 400 A.

Table 5. Measured (T_{meas}) and model-calculated (T_{calc}) temperatures of the fuse under 200 A.

Thermoelement	T_{meas} [°C]	T_{calc} [°C]
TE_1	47.57	57.83
TE_2	51.74	58.24
TE_3	46.98	57.67
TE_4	51.81	58.09
TE_5	50.19	58.83
TE_6	47.91	58.66
TE_7	47.26	60.10
TE_8	49.81	59.98
TE_9	50.47	63.68
TE_{11}	75.18	68.31
TE_{13}	76.46	68.31
TE_{14}	50.59	64.66

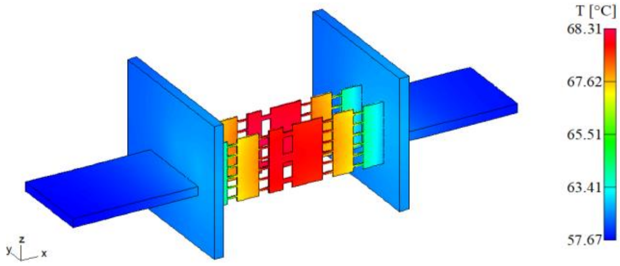

Fig.5. Temperature arrangement under 200 A.

The results presented in Tables 4 and 5 shows deviations between measured and model-calculated temperature, which means that the catalogue values for thermal properties of fuse links used in this simulation model are not completely reliable. The next step would be identification of these factors for more reliable calculations.

4 Conclusion

This paper describes the simulation model of a low voltage melting fuse. The simulation model is formed as a 3D fuse model using the Finite Element Method and includes the electric and thermal material properties and boundary condition values.

The authors used the simulation model in order to calculate the temperature of fuse using the catalogue values of material's electric and thermal properties. The temperature measurements were carried out in a laboratory using thermosensors, which were placed in the inside and outside of the fuse.

Comparison between measured and model-calculated temperature shows deviations. The agreement primarily depends from the accuracy of the input data (i.e. material properties), which is why is this model needed to be upgraded.

Regardless of that, this model is suitable for temperature calculation of this type of electric fuse. The user can get an idea about the arrangement of the temperature of the fuse and its parts. Usage of this simulation model is especially recommendable, if there is no possibility for measurement in a laboratory using the real fuse.

References:

[1] SIST EN 60269-1:2007. Low-voltage fuses – Part 1: General requirements. SIST, Ljubljana, 2007.

[2] A. Wright, P.G. Newberry, *Electric Fuses*, 3rd ed., IEE: London, UK, 2004.

[3] J. Pihler, *Switchgear of Electric Power System*, 2nd ed., University of Maribor, Faculty of Electrical Engineering and Computer Science, Maribor, pp. 1-273, 2003.

[4] Program tools EleFAnT 3D, Graz, Austria, Inst. Fundam. Theory Electr. Eng., TU Graz, 2000.

[5] A. Hamler, S. Grill, J.P. Cuković, "Thermal analysis and temperature calculation for the NV melting fuse," in *9th International Conference on Electrical Fuses and their Applications (ICEFA)* 2011, Maribor, 2011.

[6] R. Holm, *Electric Contacts Theory and Application*. 4th ed. Springer-Verlag Berlin Heidelberg GmbH, 1981.

[7] T.M. Tritt, *Thermal Conductivity: Theory, Properties, and Applications*. Kluwer Academic/Plenum Publishers, New York, 2004.