Subject: Pure Silver Fuse Element – Why does pure silver remain as the sole choice?

Studies on MV Fuse Element Materials

Various metals have been tested in Germany since 1940s to check whether they are suitable for use as an alternative to pure silver. Particularly in Eastern Germany, when silver was in the "precious metal" class, these works were highly appreciated but never resulted in replacement of silver with any other metal.

Since 1976 to the present, ICEFA (International Conference on Electric Fuses and Their Applications) conferences have been held with the participation of experts in the field of fuse throughout the World (globally competent academicians and industry-leading R&D specialists).

Fourth of the aforementioned international conferences was organized in the University of Nottingham with the participants from 16 countries in 1991. During the said conference, over 50 researches and articles were presented.

Use of copper/silver plated copper materials on the current line of MV fuses, which was repeatedly tried giving negative results until then, has taken a place in the researches herein.

Due to its melting temperature and conductivity values, copper attracted the attention of producers in the first half of the 1900s as the most suitable candidate. However, the experience and research have shown that it is not possible to use copper (pure or silver plated) on the current lines of MV fuses.

In those days, and of course today, the results that global fuse producers, electric utilities and board manufacturers know very well have been taken into a proven and scientific framework with this research. It is seen again that, for the current line of MV fuses, no material alternative to silver has been found yet. Copper and silver-plated copper withdrawn from this candidacy years ago due to the known problems (to be detailed in the letter).

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Tests performed within the Researches and Findings

- Breaking tests: 3.6 kV 10A fuses were individually tested (i1, i2 & i3 tests) with copper, silver-plated copper and pure silver fuse elements at IPH Berlin laboratory and all were successful. As a matter of fact, when examining the conductivity and melting temperature of copper, it is obvious that it does not cause any trouble in this respect. Again, the main point is the fact that the pure copper gives much better results than silver plated copper in the breaking tests.

- Life tests were performed on silver plated copper (various plating thicknesses), pure silver and pure copper (Article 5.2). *As it is seen, there is no change in the resistance of the silver fuse element, so it is a material with an "unlimited life".* On the other hand, we see that the resistance of both copper and silver plated copper dramatically increase in time. (Fig 7*). So, you can see that Cu/Ag 10 (plating thickness: 10 microns) fuses possess the worst characteristics among the tested materials. Unfortunately these fuses are very similar to the ones adopted by the manufacturers of these type of fuses; as they are least expensive*. It should also be noted that, since this is an academic study, silver plated coppers of 150 microns and 260 microns have also been tested. Still results are not satisfactory at these extremely high coating thicknesses. Moreover, in practice such products would not make any commercial sense for the manufacturer. And silver plating thickness is generally kept at a minimum.

- Finally, as far as the life tests of fuses in §5.3 are concerned, the truth is revealed. *When a 36 kV 10A fuse is loaded at nominal current, its life expires in approximately 100 days.* While the fuse is expected to continuously carry the nominal current without heating, the temperature therein is too much for the fuses with copper current line, and their life expires in approximately 100 days.

Oxidation Process

As known worldwide and as stated at the beginning of the research (different researches in this respect are also referred to at the beginning of the original ICEFA conference notes), the fuse current line will come into contact with oxygen. And, copper is oxidized reacting with oxygen. The aforementioned current line is the cause of the change in characteristic and expiration of the fuse life in a short time.

- Oxidation typically occurs in two ways. The two factors described below are chemical processes that are simultaneously active in oxidation of copper or silver plated copper fuses.

    1- Diffusion between metals: Plated silver and copper strip will form an alloy with a higher resistance. (All characteristics of this alloy other than the resistance change. E.g. melting temperature. Referring to the other

previous researches, while the melting temperature of silver is 960.5 °C and the melting temperature of copper is 1083 °C, the lower limit of the melting temperature of the alloy decreases up to 779 °C.)

2- Copper oxidation: Silver plating is evidently not an effective protector against oxygen. It is also obvious in the research. As it is seen in the Fig. 7, nickel plating of 7.5 microns gives better results than silver coating of 260 microns. (coating thickness of 260 microns is a value that can never be used in practice but can only be subject of such an academic study.) ***Therefore, contrary to some arguments, the reason of silver coating has got nothing to do with slowing down the oxidation. The sole reason is easiness of spot welding***. But, again it is seen in the same graph (Cu/Ag 10), while silver coating makes spot-welding process easier, it makes copper which is vulnerable to oxidation worse. ***In other words, when copper is coated with silver in small proportion, breaking characteristic of the copper becomes worse and lifetime gets even shorter. Unfortunately, this is the common practice of low-end suppliers.***

- When oxidation starts, the conducting cross-section decreases; so, the heat further increases. Oxidation, like all other chemical reactions, accelerates with heating. The process continues with acceleration, which is why the resistance/temperature increases in the graph converge infinity.

Technical Results from the Research

- *As it can be seen from the research, as the nominal voltage increases in the fuses with copper fuse element, the life of the fuse is shortened dramatically.* Higher the fuse, bigger the heat dissipation problem and faster the oxidation. ***Life of a fuse decreases to days at a voltage level of 36 kV used, in our domestic market. At 12 kV and above there is no reasonable and possible range, where copper/silver plated copper may be used as a fuse element.***

- *Likewise, at higher nominal currents, the oxidation will occur much faster.* So, life of the copper (or silver plated copper) fuses will also be shortened. In this research, the tests were conducted on 10A fuses from 3.6kV to 36kV. ***Life of the fuses with copper current line at an amperage higher than 10A will be less than 100 days.***

- *One can expect even worse results in case of using these type of fuses indoors, which means, exposing these fuses to higher temperatures.* Fuses used within the switchgears (especially RMU) would be a very good example for this. At such high

temperatures, temperature rise and ageing becomes even bigger problems for these type of fuses. ***Fuses that expire in such a short period as 100 days will complete their lives even earlier if loaded at nominal current in such an environment***. While heat dissipation is already too challenging due to the ambient conditions, it is normal to expect further shortening of the life of copper or silver plated copper fuses.

- *We should also keep in mind that characteristics of such fuses will change day by day, due to decreasing cross section of the fuse element. Resistance of the fuse and all other technical characteristics will shift day by day, once oxidation reaches a certain rate.* Therefore, aside from the date when the fuse will complete its life, the fuse used changes characteristic throughout its life due to the temperature. ***This creates great uncertainty as to when the fuse will trip and also great danger for the system***.

***IMPORTANT NOTE*:** Once the short circuit is interrupted, switching voltage will come into play. As well known, the switching voltage of the fuse should never exceed the insulation voltage of the system/equipments. In this respect, pure silver seems to have the best characteristic and the silver plated copper seems to have the worst characteristics (the remarkable point is that the pure copper has much better characteristics than the silver plated copper). See Fig. 2.

This constitutes a bigger challenge in short circuit protection for higher nominal rated current fuses. The task of the fulgurite formed during the short circuit (the material formed by the current line and the quartz sand together) is to make the environment insulated again in a short time. As seen in this study, copper is oxidized as opposed to silver. Copper-oxide is a semiconducting material and as it is part of the fulgurite, it prevents/delays the primary function of the fulgurite. This leads to formation of repetitive arcs after the first short circuit current. The prevalence of this is directly proportional to the rated nominal current of the fuse (more evident in higher rated currents). This is another risky aspect of using copper as a fuse element material.

Conclusion

As per IEC 60282-1 Clause 4.7, "fuses should be able to carry the nominal current load on a continuos basis ***without detoriation*** and ***without exceeding the temperature limits***". As shown in detail in this study, copper/silver plated copper and similar metals are unable to comply with this fundamental requirement. Moreover, they create major threats to the network, humans and the environment.

To date, pure silver remains as the sole proven material for fuse elements. As a global practice, copper or silver plated copper have never been considered as a candidate for use, due to the reasons highlighted in this study. This is an evident fact

which requires no further debate, apart from some markets where low quality products are welcomed.

Unfortunately, the results of studies abroad, which started more than 70 years ago and ended several decades ago, are still not known to many manufacturer in our country and, even worse, not investigated.

We believe it is vital that to keep the end users well informed. Particularly, about such a subject where it is not easy to find relevant literature and test results. It is known that some manufacturers have tried/been trying to push these products into some networks; without informing the end-user in advance. So, we sincerely hope that this study will help the end-users, utilities and OEMs to be aware of this crucial matter.

Costs of HV fuses are relatively insignificant. But their task is to protect transformers and other high-cost equipments from the dramatic impact of short-circuit currents. By selecting the right fuse and with supply of quality products, it is possible to save tremendous amount of operating costs in relation to these products. Putting aside the financial aspect (re-supply of products, workmanship, etc.), the explosions caused by fuse in many regions lead to injuries, life-threatening situations and environmental damages (fire, forest fire, etc.).

Fuses, in many ways, ***are similar to the airbags*** in our vehicles. You would, preferably, even forget about the airbags, until you come across an accident. And in case of an accident, you'd want to be completely sure that your airbags/fuses work perfectly, regardless of the conditions.