A Study on the Cause of Failure and a Method for Improvement of Fuses

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1. Introduction

International standards require a protection function to prevent damage to electrical equipment and the loss of life from overcurrent. To reflect these requirements, nuclear power plants and industries use a variety of fuses in electrical and I&C equipment. In general, when excessive current is applied to a circuit, an internal element of fuses melts and then the fuse performs a safety function to cut off the overcurrent to protect the circuit.

Fuses perform normal operation in which an open circuit by overcurrent. However sometimes, fuses perform abnormal operation in which an open circuit by malfunction. The cause of failure can be numerous occasions even though temporary, so conducting a failure analysis is too difficult and un-representable [1].

The method of failure analysis can be a X-ray image interpretation which analyze fuse element melting condition. The cause can be determined through this method and a corrective action determined.

2. Fuse blow down analysis

2.1. Cause of Melting

A fuse may be blown caused by a rush current, the terminal block and cable connection instantaneous short circuit, a surge by lightning or fault of power system and ESD(Electrostatic Discharge) on the human body, etc.
It is very important to derive the fault cause because corrective action is different according to different failure causes.

2.2. Fuse blow down test

Our fuse blow down test used a fast-acting glass fuse. Test sequences involved an appearance inspection, a blown fuse test, x-ray irradiation and inspection of the fuse's melted element. We performed blown fuse tests with a surge (1.2/50µsec, 5kV & 8kV), ESD(~15kV) and an overcurrent test according to the current size. Fig. 1 shows the x-ray irradiation of the fuses.

2.3. Cause analysis of element melting

The X-ray images of the melting of the fuse element in the surge test are shown in Fig. 2. When 1.2/50µsec wave 5kV was supplied to the test fuse, the element did not melt. However about 90% of the fuse element was melted when the given voltage was 8kV.

Fig. 1 The x-ray irradiation of the fuses

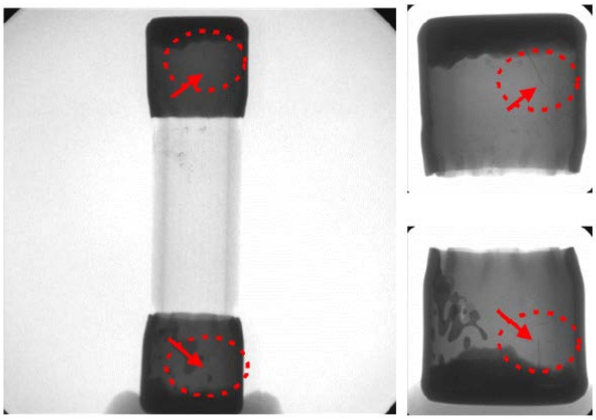
Fig. 2 The x-ray image of a fuse blown by a surge

According to the X-ray image interpretation in the surge test, the open gap of the element was relatively long and there was no vestige of melting [2].
When the ESD(~15kV), which can flow into the human body, was applied to the fuse contacts using an ESD application apparatus, the element did not melt [2].
For simulation on the most frequent and various situation of fuse element melting, two and five times its rated currents were used as overcurrent test voltage. X-ray images of the melted fuse elements are given in Fig. 3.

As a result of overcurrent (twice its rated current) test, one or two fuse element open is shown by X-ray image interpretation. The open gap was shorter than it was in the surge test. The melting phenomenon occurred at the end of the open part. In overcurrent (five times its rated current) test, the number of fuse element openings was significantly increased, the open gap was very short and the melting phenomenon appeared at the end of every single open part. When overcurrent (fifteen times its rated current) test was performed, the opening gap was too short to find the element trace and the melting phenomenon was seen at the end of every single opening part [3].

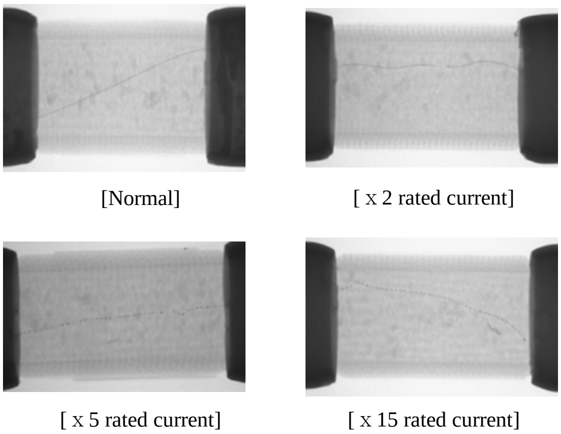

Fig. 3 An image of a fuse blown by overcurrent

2.4. Transient phenomena's cause and improvement method

A surge can be caused by lightning and power system failure. In order to prevent surges in electrical and I&C equipment, a surge protector of sufficient capacity should be installed and grounded properly so that the system would be designed to not blow a fuse caused by surges as well as the equipment would be protected. Fig. 4 shows the general configuration of a surge protector installed and grounded to block incoming surges.

Overcurrent can be caused by capacitive coupling of a power cable, inductive coupling between cables, inrush current when breaker and inductive loads start, instantaneous short circuit in the cable connections on terminal block. Particularly a short circuit in the cable connections on terminal block can occur to melt fuse element due to overcurrent by tin whisker (Fig. 5) [3].

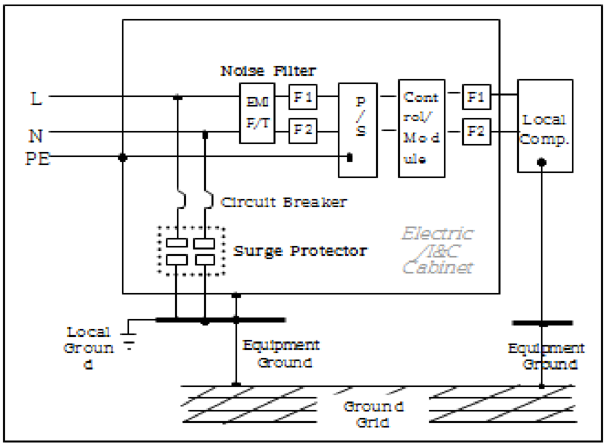

Fig. 4 General configuration of SP installation and grounding

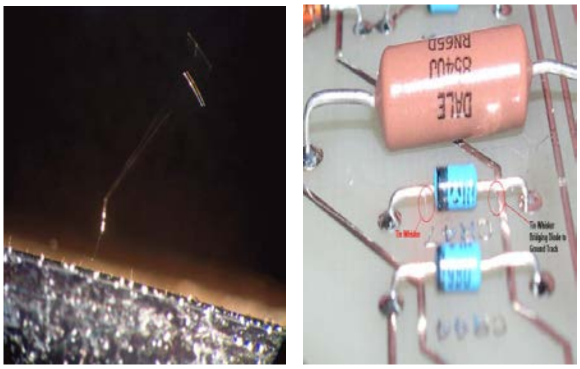

Fig. 5 An image of a tin whisker

To prevent overcurrent due to capacitive coupling, the signal and power cables must be disconnected and a shielded cable with one end grounded must be used.

To prevent overcurrent due inductive coupling, shielding of a ferromagnetic material of high permeability and a twisted cable must be used.

When breaker and inductive loads are started, an inrush current can be controlled by inverse voltage and current protection. The tin whisker can be eliminated with the air gun, soft brush and electric circuit cleaner during maintenance.

3. Conclusion

Fuses have an important function such as protection for electric circuits and people against overcurrent flows. However, fuse elements can sometimes be opened by not only normal situations, but also abnormal phenomenon for failure. When the abnormal phenomenon is temporary, analysis of its cause is very difficult and its reproduction is impossible in many cases.

In this paper, we determined that the root cause of fuse element melting by a transient phenomenon can be analogized by analyzing the element melting figuration with an X-ray verification test. We also suggested improvement methods regarding failure causes.
Furthermore, we demonstrated a cause analysis and improvement for various fuse failures by performing an X-ray verification test. The application of the analysis and method will contribute to the improvement of the reliability and safety of plant equipment.

REFERENCES

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[3] "Review on the fuse melt of plant control system of sinkori #1&2" , KHNP Technical Report, October 2015.