Damage avoidance due to the use of high voltage fuses and temperature monitoring

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Abstract
Modern miniaturized electronics allows today the thermal monitoring at high voltage fuses too. With this possibility of thermal monitoring the uncontrolled switch off of this HRC fuses and therefore damages of electrical equipment due to the partial melting or melting of fuse-elements can be avoided.

Introduction
Today HH-fuses are an equipment which is often used because of its economically priced possibility to switch off short-circuit currents in a reliability way. This capability protects from the effect of the thermal and dynamic exposure of short-circuit currents.

Fig. 1: destroyed medium voltage switchgear as a result of a blown-up HH-fuse

Nowadays unexpected switching-off of HH-fuses is reported in conjunction with damages at electrical equipment of switchgears.
Fig. 1 shows blown-up HH-fuses in a medium voltage switchgear, which led to a totally destroyed switchgear due to the occurrence of a three pole short-circuit current linked with arcing.

The cause for the failure of HH-fuses can be very different. Some failures are based on the partial-melting or melting of some fuse-elements within the fuse. These melting of fuse-elements changes the time-current-characteristic of the fuse as well as the power dissipation to higher values. Root causes for increased stress for fuses can be

- short circuit in transformer coil with long term failure current /1/,
- transformer operation above rated power /1/,
- lower mapping of the fuse to transformer rating than necessary /1/,
- unacceptable temperature around the fuse, imperfect heat dissipation /1/,
- inadequate contacting /1/,
- partial melting of fuse-elements as a result of thunderstorm /1/,
- wrong engineered switchgear,
- strongly pulsate currents,
- mechanically induced vibrations.

The ageing caused by pulsated currents is thinkable e.g. the injection of renewable energy sources like photovoltaic (PV) or wind energy converter (WEC). The sudden changing of the cloud structure at photovoltaic plants (PV) or the rapid change of wind at WEC causes oscillations of injected currents. Similarly current oscillations may be generated by mechanical oscillations of the tower of a WEC, the voltage controller and the pitch controller. Just as well mechanical oscillations are transferred to the fuse and the built-in fuse-elements. The continuous transfer of oscillations to the fuse-elements will lead to a break of the fuse-elements due to the reaching of end of the endurance limit (Wöhler-characteristic). The end of the endurance limit (Wöhler-characteristics) was not subject of scientific research projects till now.

Often the degradation of fuses is linked with the change of the power dissipation because the structure of the internal fuse-elements changed. Because of this phenomenon a test set-up was built up to examine the possibility to develop a system for thermal monitoring of high-voltage hrc fuses.

Test set-up

The test set-up consists of a controllable voltage source, a current meter as well as a multi channel temperature data logger.
The test set-up is designed according the requirements of the standard DIN EN 60282-1 /2/.

The investigations were done at HH-fuses of the type SIBA GmbH HH-backup fuses with the following data:
type SSK 20/36 kV, “e“ = 537 mm, 80 A, RC 71 A, operation at standard conditions: power dissipation 153 W, cold resistance 21 mOhm.

Fig. 2 shows, that the fuse operates within a fuse tube. This fuse tube reduces the possibility of the power dissipation and heat transfer to the environment. Some manufacturer of switchgears recommends lowering the permanent current to the half of the rating of the high-voltage hrc fuses fuse because of this fact.
The operating shown in fig. 2 is according to the use within sf_6 insulated medium voltage switchgears.

Additional advices are given by the manufacturer of switchgears for the limits of the maximum power dissipation within the rated operation, that shall not be exceeded /3/.
It is problematic or quiet impossible to monitor the power dissipation or the temperature while the fuse is in operation.
If a fuse-element is interrupted the power dissipation will increase while the fuse is still in operation at nominal current flow.
Referring to fig. 2 and the application of the usage of a fibre reinforced insulating fuse tube the increasing temperature may lead to a decrease of dielectric, mechanical and sf_6 gastight characteristics and an upcoming failure within the switchgear will arise.
The realization of the aim of a thermal monitoring has to consider the mechanical access to the fuse. Due to the location of the fuse this access isn´t given while the fuse is in operation because of high voltage and personal safety.

Technology of the sensor
The measurement of the temperature of an electrical device connected to high voltage may not be done with a wired energy source. An independent electrical energy source is needed to supply the electronics. Due to this fact of personal safety and high voltage, batteries or rechargeable batteries need to be used. This has the disadvantage of maintenance of these batteries combined with the switch off of the switchgear to get access to the temperature sensor unit to change the batteries or rechargeable batteries.
With the usage of a thermoelectric generator, which will convert thermal energy to electrical energy from the environment of the fuse, it will be possible to power the electronics.
The availability of a sufficient temperature difference is necessary for powering of the electronics. Because of this it is necessary to investigate the thermal situation around the fuse tube and the fuse.
These investigations were done with the usage of the test set-up according fig. 2.

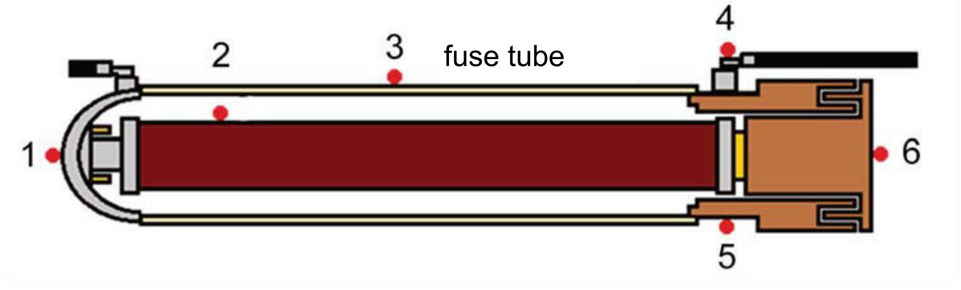

Fig. 2: Possible positions for thermal monitoring /5/

Fig. 2 shows six possible measuring points where the thermoelectric generator may be placed. While the thermal investigations were done the mechanical available space to place the sensor later on was checked too.

The choice of the location of the temperature measuring sensor needs to consider that the measuring points 1, 3, 4 and 5 are located within the sf_6 gas-filled compartment.
At the above listed measuring points the temperature sensor may be fixed at the time while the switchgear will be assembled only.
It is quite advantageous to use the measuring point 2 or 6. With measuring point 6 exists the possibility to mount the sensor within a zone that ensure the protection against accidental electrical contact. But this measuring point is located far from the heating area of the fuse so that a great delay in the thermal measurement of the temperature will arise.
Because of all this considerations position 2 was to favour linked with the technical necessity of enough space for the sensor, a sufficient temperature difference for powering the electronics and a minimum influence to the insulation coordination around the fuse.

An already existing solution for the measurement of the temperature at busbars located at high voltage level provides a principal solution that needs to be adapted to the existing problem of monitoring the temperature at fuses while these are in operation /4/. There the measured temperatures are transmitted via radio frequency to a receiver placed outside the high voltage area. As well there is the necessity of a sufficient temperature difference needed to power the electronics.
Fig. 3 shows the measuring points where temperatures are measured while the fuse is in operation and the nominal current flows. Additional measuring points are located 10 mm above the measuring points at the surface of the fuse to represent the upper surface of the temperature sensor due to the fact, that a temperature difference will be needed.

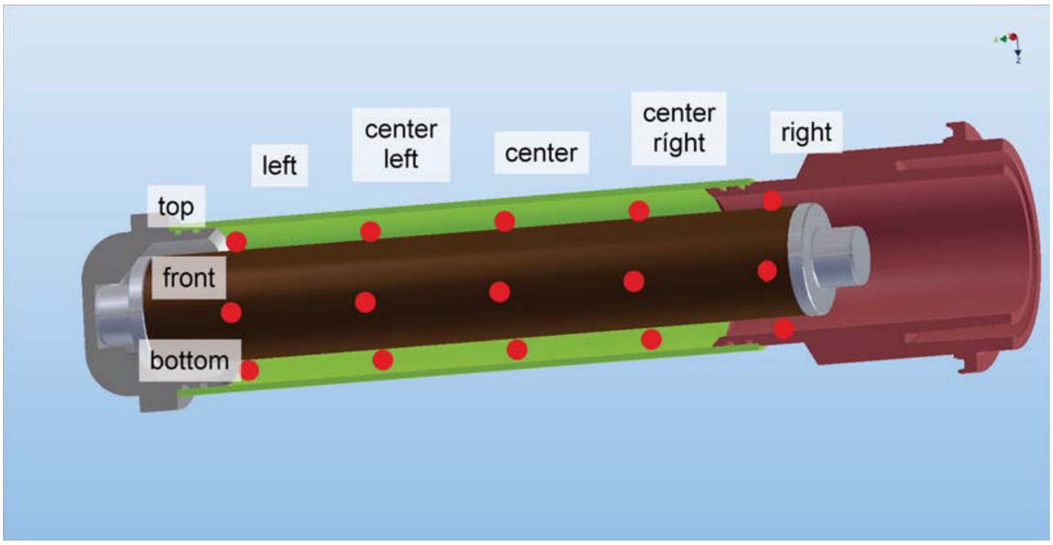

Fig. 3: possible sensor locations

The following fig. 4 and fig. 5 show the measured temperatures on the top of the fuse and within a distance of about 10 mm above the particular measuring point. This will simulate the height of the later fielding temperature sensor and his subsequent environmental temperature.

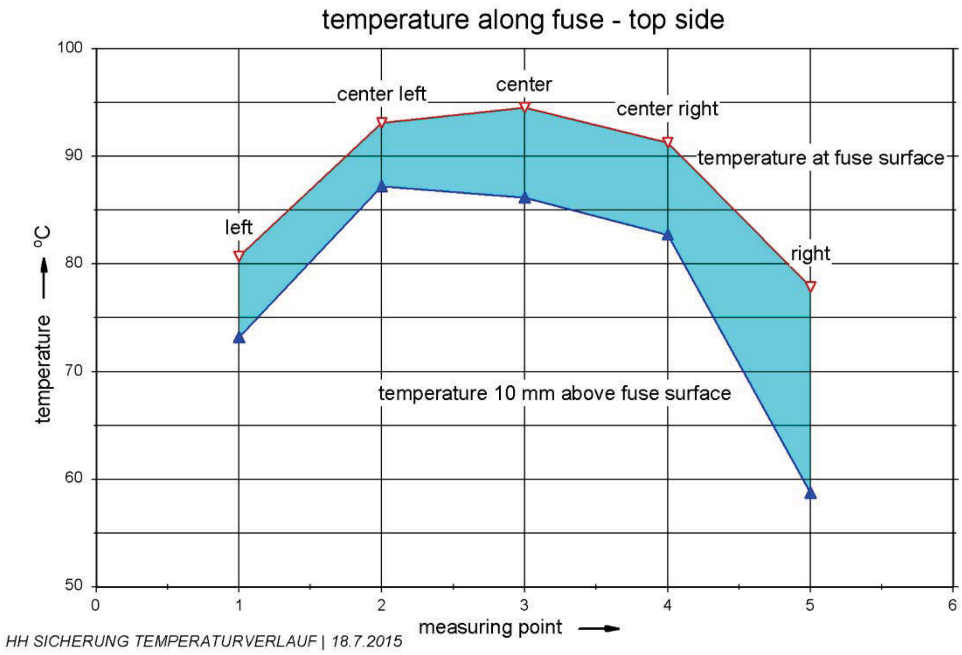

Fig 4: Difference of the temperature along fuse – top side, red curve: temperature at fuse, blue curve: temperature in the distance of 10 mm above the fuse

Both diagrams show that the temperature differences on the surface of the fuse are clearly distinct and towards the edges sink clearly. The subsidence of the temperatures towards the edges of the fuse can be traced back to thermal conduction of connecting fittings. At the same time a thermal gas flow exits within the fuse tube that leads to a thermal equalization. Because of the already achieved results the favourite position to adapt the thermoelectric generator is a bottom side and centred of the fuse. Fig. 6 shows the planned position of the energy self-sufficient temperature sensor.

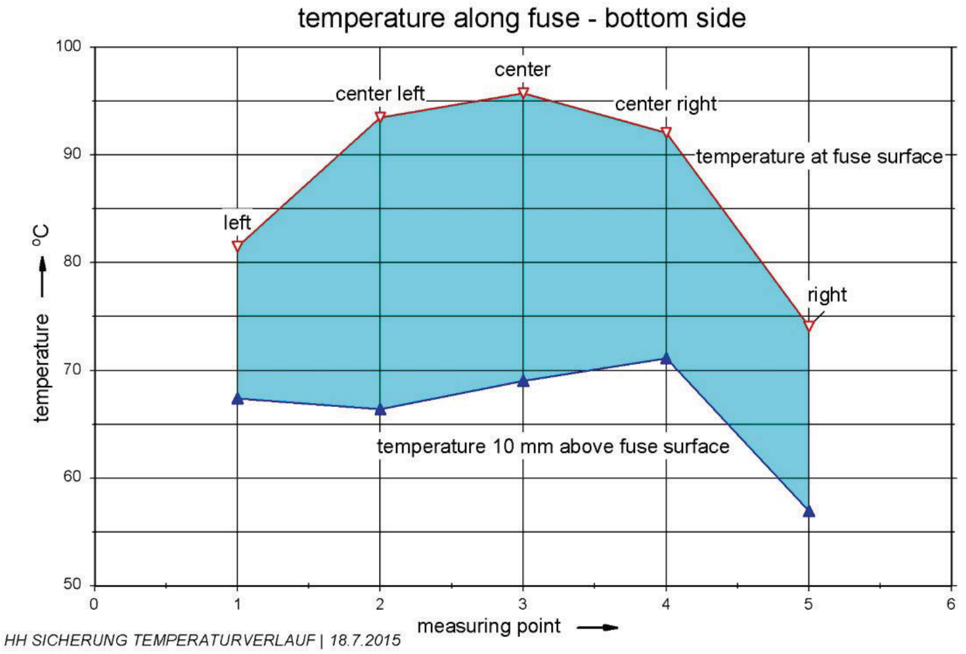

Fig 5: Difference of the temperature along fuse – bottom side, red curve: temperature at fuse, blue curve: temperature in the distance of 10 mm above the fuse

Current state of the investigations - conclusion

At the moment the mechanical manufacturing to the metal body of the prototype is going on. With the availability additional investigations will follow to examine the dielectric influence to the fuse and the fuse tube, e.g. measurement of the partial discharge inception and exception voltage, impulse withstand voltage and continuous withstand voltage with and without the implementation of the temperature sensor. Based on the actual results of the investigations fig. 6 shows the actual position of the temperature sensor with a sf_6 gas insulated switchgear for thermal online monitoring.

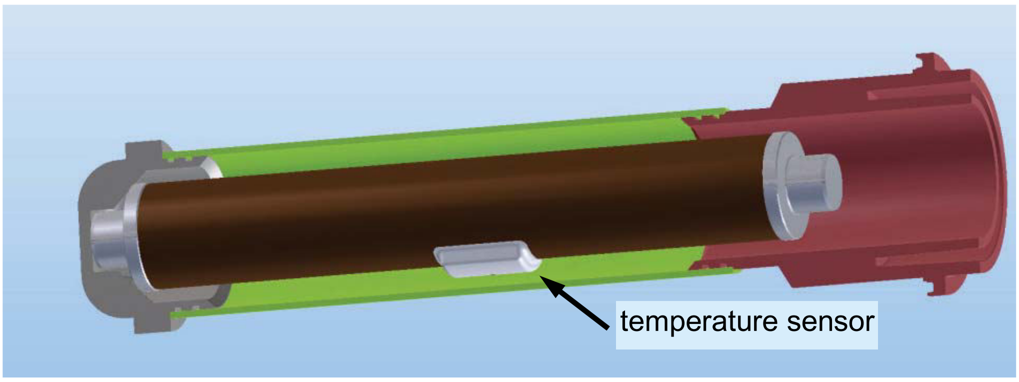

Fig. 6: Fuse with adapted temperature sensor

There exists the necessity to influence the insulation strength as less as possible while the sensor is implemented. Additional investigations will be realised while the sensor operates within real sf_6 gas insulated switchgear. These investigations will be finished at the end of 2015.
By the availability of the temperature sensor it will be possible to measure within operation the temperatures of HH fuses and to notify all electronically available media or one control level on a display.

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