SOME FACTORS INFLUENCING BREAKING PERFORMANCE OF HIGH VOLTAGE FUSE CUT-OUTS

V R Smart*, M H Sheng**, S S Douglas***
*GEC ALSTHOM Low Voltage Equipment Ltd, Liverpool, UK , ** Xian High Voltage Apparatus Research Institute, Xian, China, *** Liverpool John Moores University, Liverpool, UK

Abstract: This paper reviews some factors influencing the breaking performance of high voltage expulsion fuse cut-outs, and makes some proposals for the design, operation and testing of high voltage fuse cut-outs.

1. General:

The simple construction, reliable performance, low cost, and easy maintenance of high voltage expulsion fuse cut-outs have resulted in their widespread application throughout the world. In power distribution system from 6 kV to 40.5 kV the world demand has reached over a million units per annum, for short-circuit and overload current protection of transformers, cables and other distribution apparatus. So any improvement in the design and application of this equipment could significantly improve manpower and material usage efficiency. However, unsuitable use of fuse cut-outs can reduce their performance leading to short-circuit current interruption failure and dangerous incidents.

From the short-circuit current interruption tests of the new GEC ALSTHOM type GA-15, GA-27, GA-38 series high voltage fuse cut-outs we have found that fuse carrier design, fuse link construction and mounting arrangement and environmental conditions have a significant influence on performance. Our work provides an opportunity to review the established body of design knowledge associated with this type of equipment.

This paper reports on a series of experiments and is a continuation of the research reported by M H Sheng [1]. A literature search indicates that there has been no other work published in this area.

2. The influence of fuse carrier design:

There are two types of construction used for the fuse carriers used in high voltage fuse cut-outs in the world at present. The first is single venting construction, and the second is double venting construction combined with a pressure relief cap, Fig 1. The significance of the double vented design is that at high levels of fault current the unit double vents. However, for low fault currents the pressure relief cap enables the double vented unit to operate as a single vented unit. This construction solves the problem of interrupting high and low currents with fuse cut-outs, increasing the interrupting current capability.

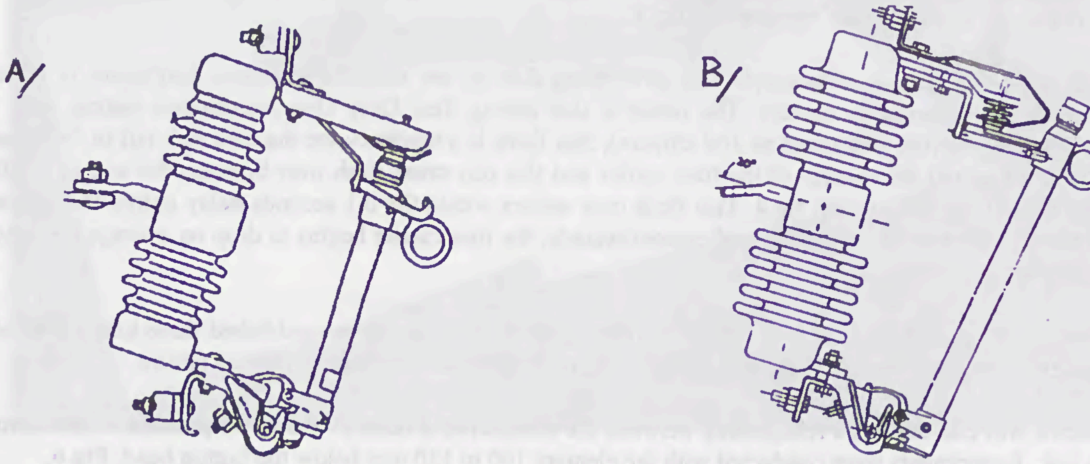

Fig 1: Alternative fuse carrier constructions. A, single venting. B, double venting.

Double venting has other advantages such as:

- Fault diagnosis: If the pressure disk is still in place then the fault is probably an overload. If the pressure disk is not in place then the fault is probably a short circuit. This assists the line engineer to identify the type of fault.

- Health and Safety: If the line engineer connects a fuse carrier onto a fault then half the gases are expulsed vertically, away from the engineer. This reduces the relative risk to the engineer.

3. The influence of fuse link construction:

Fault current interruption testing at the GEC ALSTHOM Manchester test station, UK, and Xian High Voltage Apparatus Research Institute test station, China, indicates that the position of the fuse element within the fuse link has a significant influence on the interrupting capability of the fuse cut-out unit. Under fault conditions the fuse element vaporises and the lower part of fuse link will be rapidly drawn out from fuse carrier as a result of the tensile force from the spring and spring plate at the bottom of the fuse carrier. Arcing commences when the element vaporises and the arc is extended as the fuse link is drawn out of the fuse carrier. A large quantity of arc quenching gases are released by the fuse carrier inner lining as a result of the incandescent arc temperature. The gases cause a rapid increase in pressure within the fuse carrier, which assists the expulsion of element material and fuse link. The arc is extended and cooled, such that the arc ceases when the applied voltage passes through zero and establishes higher dielectric density against discharge under the recovery voltage. Finally the fuse carrier swings down and gives a visible disconnect point.

At present, the most of the fuse links used world-wide for this application have the fuse element immediately below the button head, **Fig.2.** In this type of fuse the element is located adjacent to the brass inner wall of the upper moving contact casting. Under fault conditions the arc can not release gases in the fuse carrier until the arc is drawn below the level of the upper casting under the tensile force of spring and spring plate, which is on average a distance of 100 to 120 mm. Only when the arc has reached the fuse carrier inner lining are arc quenching gases released and the arc will then be quenched at the next current zero point.

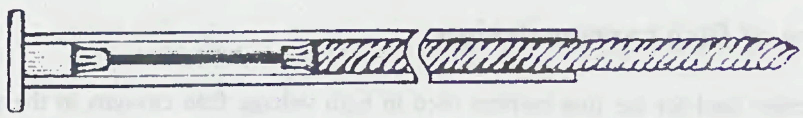

Fig.2 Fuse link with element immediately below the button head

Under fault conditions the element is vaporised but the fuse link tail is expulsed from the fuse carrier and describes an arc centred on the lower contact termination, **fig.3.**

From our high speed camera photographs we have been able to see that the vibration amplitude is directly proportion with the interruption current. The result is that during Test Duty One interruption testing with the maximum rated current fuse link (such as 100 ampere), that there is a tendency for the fuse link tail to "whiplash" such that the tail contacts the outside of the fuse carrier and this can cause flash over between the end of the fuse link tail and the top contact casting, **fig.4.** This flash over occurs within the 0.1 seconds delay before the fuse arm begins to move. According to our high speed camera records, the fuse carrier begins to drop on average 0.1 second after interruption commences.

Examination of the oscillogram from such a flash over shows that the arc is re-established three half waves after commencement of interruption (0.03 seconds), **fig.5.** This is considered to be an interruption failure.

Our hypothesis was that there is a relationship between the creation of a flash over and the position of the element in the fuse link. Experiments were conducted with the element 100 to 120 mm below the button head, **Fig.6.**

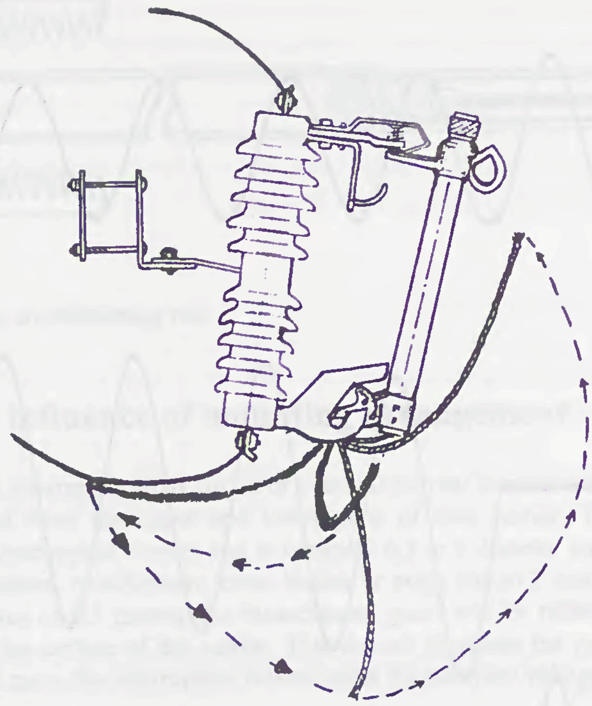

Fig.3: the motion arc of the fuse link tail during interruption test.

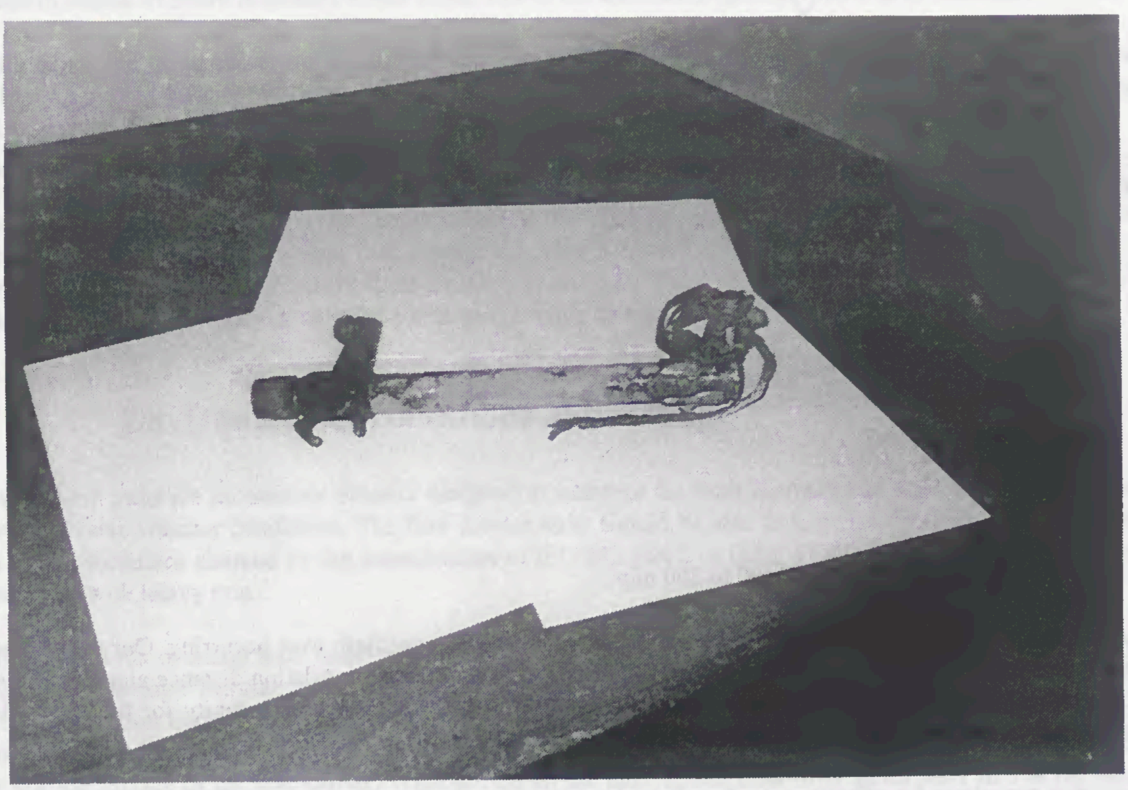

Fig.4: Photograph of fuse carrier showing result of flash over between the fuse link tail and top contact casting.

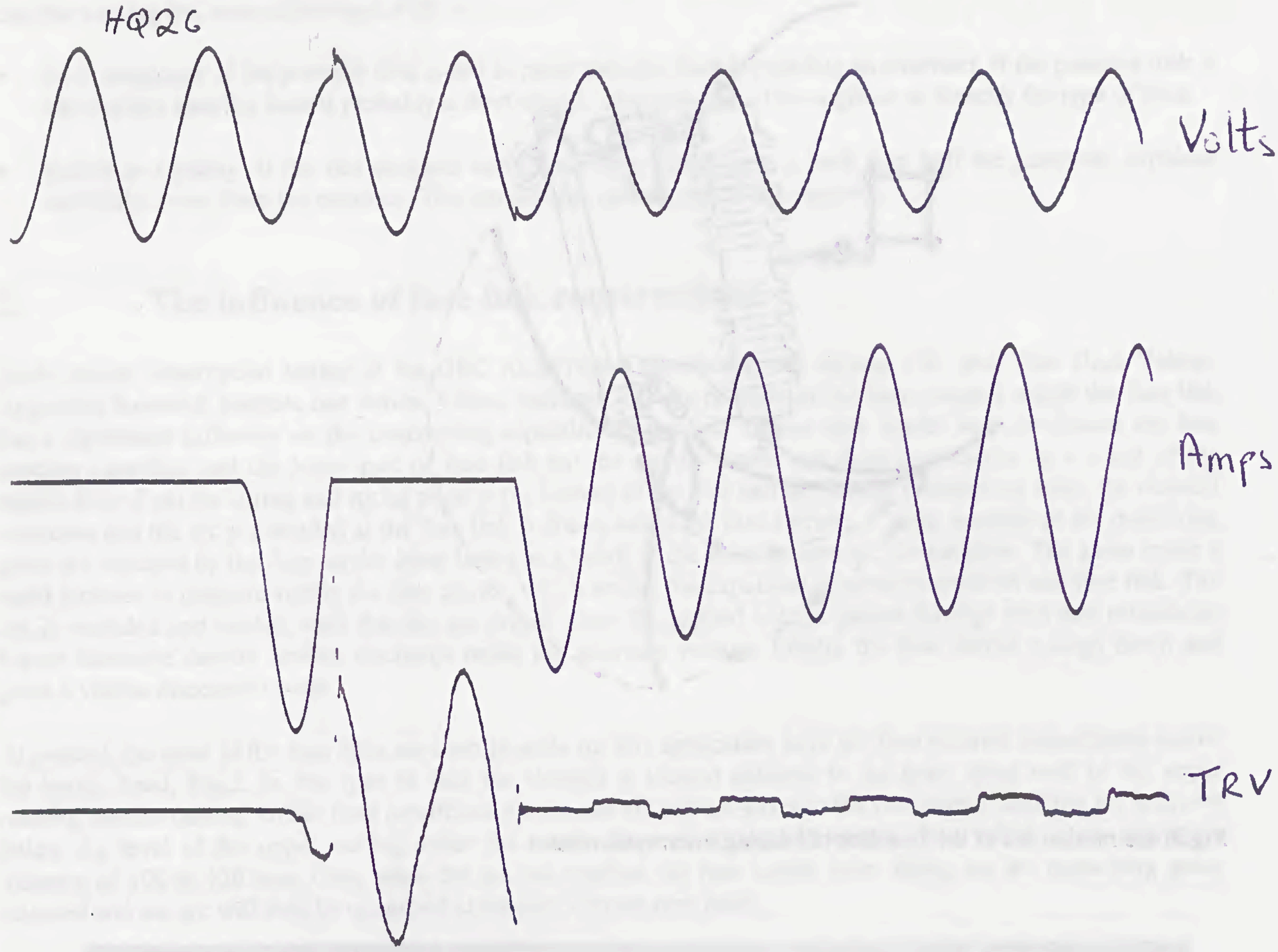

Fig.5: Oscillograms of fault current interruption flash over at 22 kV, 100 ampere rated fuse and 5 kA interrupting current 5 kA from GEC ALSTHOM Manchester testing station of United Kingdom.

Fig.6 Fuse link with element offset by 100 to 200 mm.

The same tests were repeated using fuse links with offset elements without flash over occurring. Our conclusion is that this was because the fuse link tail was 120 mm shorter and as a result the insulation distance along the outside of the fuse carrier was increased by 120 mm, preventing flash over. There is an opportunity for further work to theoretically investigate and model the dynamic behaviour of the fuse tail.

An alternative technique for offsetting the fuse link element within the fuse carrier is to use an arc shortening rod with a threaded connection to the fuse link, **Fig.7**. This technique is not as efficient as using a fuse link with an offset element because of increased cost of manufacture. Also, the arc shortening rod can be damaged as a result of fault current interruption, which means that the rod must be replaced.

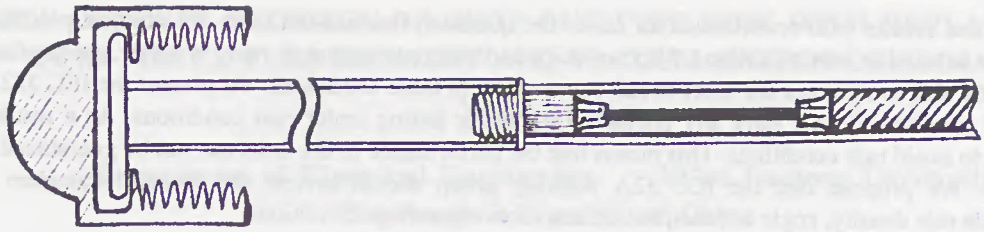

Fig.7 Fuse link with arc shortening rod

4. The influence of mounting arrangement

When a fuse cut-out interrupts a short circuit or overload current incandescent gases containing a quantity of copper vapour are expulsed from the upper and lower parts of fuse carrier. The length of the gas flare is directly proportional to the interrupted current and is typically 0.3 to 0.4 metre long with a diameter about 0.1 metre. If there are any conductors, transformers, cross beams or posts within 2 metres from upper and lower parts of fuse carrier within a radius of 0.5 metres, the incandescent gases will be reflected onto the fuse carrier and deposit a layer of copper on the surface of the carrier. This deposit increases the possibility of a flash over along the fuse carrier, which could cause the interruption failure under the recovery voltage.

Our hypothesis was that the mounting arrangement also influenced the spark creation characteristics of the equipment. Experiments to test this hypothesis were conducted at Xian High Voltage Apparatus Research Institute, China, using the test procedures specified in Australian standard AS1033.1 [2].

If the expulsion gases were not properly controlled then there was reflection of the gases causing flash over along the fuse carrier, burning the lower contacts and creating liquid copper droplets. These were found to make burn marks in excess of 3 mm diameter, which could lead to the creation of ground fires in arid conditions.

If the expulsion gases were properly controlled then the gases contained a minimum quantity of copper vapour, which was cooled prior to contact with the ground. As a result there were no burn marks and a significantly reduced risk of ground fires.

Some designs of fuse cut-outs use a special spark trap device under the fuse base. This device is used to change the direction of the incandescent gases and increasing the cooling distance for the copper vapour. However, our conclusion is that a double vented fuse cut-out mounted 3 metres or more above the ground and with a correct mounting arrangement can interrupt short-circuit currents with Class A (no spark) performance to AS1033.1. This is a simpler and more efficient solution compared to using an arc trap.

5. Environmental conditions and testing.

Fuse cut-out units are an outdoor product designed to interrupt the fault current conditions sometimes encountered during adverse weather conditions. The fuse cut-out units should be able to interrupt the fault current correctly, as per the performance claimed by the manufacturer to IEC 282 part 2 or IEEE 37.41 under the type of wet conditions associated with heavy rain.

From the results of many tests under rain conditions (the rain density 1 - 8 mm / min) at the Xian High Voltage Apparatus Research Institute and the GEC ALSTHOM Manchester testing station we found during test duty 1 at rated interruption current the first test is normally successful and the fuse carrier drops correctly. The second test using the same fuse carrier (8-10 min following the first test) are frequently a failure as a result of flash over along the outside surface of the fuse carrier. Without rain all the interruption tests from series No.1 to 5 at the same fault conditions pass successfully.

Comparing the tests results with or without rain raises the question; fuse cut-out units are outdoor products and should be able to be used in rain conditions. Short-circuit conditions can appear in rainy weather and the fuse cut-out units should be able to interrupt the short circuit successfully in these conditions. At present the IEC 282-2 and ANSI/IEEE C37 standards do not have any provision to specify testing under rain conditions. As a result most testing is phased to avoid rain conditions. This means that the performance of the units can not be guaranteed under these conditions. We propose that the IEC 32A working group should review this issue. Parameters to be considered include rain density, angle of precipitation and recovery voltage conditions.

5. Conclusions:

We believe that double vented units achieve higher breaking capacity than single vented units, assist with fault diagnosis and reduce the safety risk if a line engineer connects a fuse carrier onto a fault.

Analysis of the design of fuse links indicates that using an offset element gives an improved performance for double vented units. The dynamics of the fuse link tail needs to be theoretically investigated and modelled.

We believe that spark production of fuse cut-out units can be improved if the manufacturer specifies in detail the most efficient mounting arrangement for their equipment.

We suggest that IEC working group 32A should review the issue of testing under adverse weather conditions.

References:

[1] M H Sheng: *An experimental investigation of interrupting performance of HV expulsion fuses*, pp 37 - 42, Proceedings of the Fourth International Conference on Electric fuses and their Application, 1991, University of Nottingham. ISBN 0 9514828 1 5

[2] Australian Standard 1033.1 - 1990. *High Voltage fuses (for rated voltages exceeding 1000 V. Part 1: Expulsion type.* Published by Standards Australia. ISBN 07262 61629.