THE RELIABILITY OF HIGH BREAKING CAPACITY FUSE

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Summary: *The reliability of an electrical system is limited by the reliability of its weakest element. There are several papers on the assessment of the reliability of the electric system components, with some exceptions, one of which is on HBC fuses. The determination of the HBC fuses yearly range of faults was done from the information given by the users and by the biggest national fuse manufacturer, related to incidents during the last decade.*

Keywords: reliability, HBC fuses, fuse ageing, life span.

INTRODUCTION

When the word reliability is used, it is refereed to the behaviour of an element or equipment as a whole. The protection devices, as the fuse, belong to a special electrical element class with some differences in relation to the normal or general electrical equipment, which are expected to work properly under normal service conditions. The capability of working properly under such conditions is a passive job.

The equipment and components belonging to an electrical system, are protected by other type of devices, between them the fuse; which is in charge of the energy absorption under out of normal conditions and of the switching-off the failed circuit portion. They behave like true sentinels, conducting the current under normal conditions and interrupting when a failure takes part.

In other words, the fuse link should be stronger than the protected element (better capability for load current) under normal conditions and weaker when the circuit is on fault (start the interruption operation before the protected element become damaged). The reliability is understood as the degree of keeping as well the strength as the weakness control, thus, the fuse link should be more reliable than the protected equipment.

The clearest proof about the fuse capability for the fulfilment of both of the tasks, passive and active, is the present widespread fuse applications. Its use is due as well to the apparent simplicity as to its careful design and highly controlled manufacture.

There are several publications on components and equipment's reliability assessment, being of importance on protection devices, but limited to circuit breakers and relays. In the author's knowledge, there is only one present publication where the HBC fuses were mentioned just in a superficial way [1], being also analysed in another paper which is nearly 30 years old [2].

In reference to expulsion fuses, several papers can be found related to reliability assessment in fuses after several years of field installation [3] [4]. There is an interesting article, in which a model for fuse reliability is proposed, dividing the study in three parts, conduction (resistance), interruption and isolation based upon the different failure types [5].

On the reliability assessment studies, the fuse is always considered as an element suspicious of bad operation, being highly criticised the fact that after its operation, the replacement in order to restore the supply should be done by hand, being necessary the presence of the technician in the installation place. From the author's point of view, such concept is erroneous due to as will be further shown; the fuses reliability index is of the same order that the circuit breakers and relays ones. Besides, anyway the technician should visit the place in case that instead of fuses circuit breakers were used.

The fuse link is an "one time" device, then does not have repairing time but replacement time, which is mainly function of two components, store replacement availability and accessibility of the place of installation. In this work, the replacement time is not analysed, but this time is mentioned in the references being nearly 5.5 hrs., very similar to the 5 hrs. value given for relays in the same reference. [1]

CAUSES OF FUSE FAILURE

Every component of an electrical system can reach the failure situation, which is more possible to occur as the working time increases towards the end of its life span. That life span can be between 10 and 30 years, depending of the fuse type, being the end of life determined by the ageing, similarly to the cases of transformer oil, chemical attack to a cement pole, fungi effect on a wood pole, etc..

The useful life of an element is determined during the design and manufacture, depending of a series of service conditions considered as normal; but if during its life the conditions are harder than expected, obviously the life consume will be at a higher speed. In general, the equipment have a life span irrespectively of the load conditions, in another words the ageing always exist, for example an oil insulated transformer will be consuming its life in spite of the equipment never suffered overloads or any type of hard service, due to its components suffer degradation with the time.

The protection device type “no-one time”, have a life span mainly function of the level of interrupted currents, suffering of normal ageing yet without any operation due to its components parts, requiring maintenance work in order to extend its life.

The fuse link, protective device class “one time” has not life span, apparently due to the element does not suffer ageing under normal conditions, thus without needing any maintenance. Studies on fuses after periods between 11 and 28 years of field working under service conditions obviously variables and plenty of normal transients have been published. After these time periods, the fuses were thoughtfully tested, without finding any meaningful moving aside of the tolerance zone comparing with a new condition fuse.

Was not detected a higher difference with the older fuses in comparison with the lesser time in the field ones, which is conclusive in relation to the fact that the fuse does not suffer ageing under normal field conditions. [3, 6]

Thus, the fuse life in an electrical system can be of just a few seconds or more than several years, depending of the instant in which the fault which cause that its operation takes place. Due to that, it is impossible the forecast of the instant in which the failure will take place, it is necessary that the fuse life should be at least high than the protected element one, which can reach 30 years. [2]

Along its life, the fuse carries currents, which can change from zero to its rated value, suffering cycling with thermal variations, which can lead to mechanical effects. Besides the fuse link is subject to cross-country faults, carried by the fuse until the down stream devices operates. If the overcurrents do not overcome manufacturer-determined limits, the fuse is not going to be altered.

The high load values of any type, steady state, cyclical, transients, etc. can produce fatigue and/or ageing of the fuse. Such ageing lead the fuse to the nuisance premature operation, in other words the fuse operates faster than normal with the same current values. There is not any previous work that identifies any external cause for a slower operation or with time bigger of the characteristic I -–t curve one, except if the fuse is a marginal device, for example with insufficient M-effect material, which is a manufacture problem. [3]

The paragraph above points out a factor, which can be detrimental for the passive and sometimes for the active (interruption) fuse operation, mainly for the NH class aR and aM, HH Backup and General Purpose fuses. This situation produces a partial melting of some of the elements leading the whole fuse to operate in the prohibited overload zone. Besides this reason, practically does not exist any other external cause detrimental for the breaking capacity (active function). [7]

The consequences are very dissimilar if the fuse failure is under passive or active conditions. The total failure in passive state is just the energy flow interruption, which is nuisance and not very expensive, depending of the involved blackout cost. The passive state partial failure is normally the cause of the fuse weakening, which have serious consequences when the fuse is called to operate, due to its breaking capacity have been seriously affected.

The fuse reliability is closely related with the quality, being critical the manufacture control for two main reasons, firstly as the fuse is a protection device its control should be more strict than the protected equipment one; and secondly the fuse is a “one time” device for which its behaviour can not be checked without its damage.

When the fuse reliability is under study, results of big importance the discrimination between failure and legitimate operation; due to unfortunately and very frequently the fuse is blame of mal-operation when really have interrupted a current which can be damaging for the protected equipment. Besides, frequently the circuit designer mistake is charged to the fuse, being the device called to operate in a zone for which has not been designed to.

Following the previous analysis is considered a fuse failure when the behaviour is not the expected from the manufacture guarantee, related with any of its characteristic parameters.

FAILURE TYPES

Not all of the HBC fuse failures are of the same importance from the circuit point of view, as well in active as passive function, being necessary to specify different failure categories. They are classified in primary, secondary, tertiary and non-functional ones.

The main failure types for each class are:

a- Primary:
- interruption failure or inability for the current cut.
- successful interruption but with excessive overvoltage
- interruption with let-tru current or energy bigger than the manufacturer data maximum values

b- Secondary
- striker does not operate with successful current interruption
- operation faster than the characteristic curve values
- fuse body cracked during the interruption
- partially cut fuse element or bad welded connection, lowering the rated current.
- indicator failure (active function)

c- Tertiary
- indicator does not operate (passive function)
- temperature higher than the maximum permissible
- interruption with external effects bigger than the permissible, but without fuse explosion

d- Non-functional
- label or characteristic plate lost or illegible
- rusting on the metallic components
- small cracking and roughness of the fuse body

For the determination of the failure index, the faults called non-functional were not considered due to they do not prevent the essential fuse job.

DETERMINATION OF THE FAILURE INDEX

For the failure index determination, there are usually three data sources:

a- Manufacturer internal quality control tests
b- Manufacturer homologation or quality control external tests
c- Customer complains caused for claimed fuse failures (on field)

The information type –a- is not very reliable because it refers to elements not free for sale. This data is only applicable to the internal quality control.
The source –b- is not applicable due to it generally corresponds to test under very difficult and unrealistic conditions, done over special samples or prototypes. Also the number of tests is small and the behaviour is usually marginal.
The source –c- is also objectionable because the client claims are very inexact due to the following reasons:
- The client reports mal-operation when is not able to detect the fault or is not willing to do that. In spite of the inherent security factors, sometimes the client mistake is so big that the element behaves out of design rate.
- Asymmetry of the post-complain procedure, due to sometimes the problem is very deeply investigated but in other cases the fault is hardly considered.
- Neither all the faults are informed nor all the complains are strictly true. The number of complains is function of several factors as: fuse price, user knowledge, damage cost, etc. In other words the complain is related to the fuse, failure type and the user characteristics.

The first filtering is done after a careful study of the complain, from which it is concluded if there was a fuse mal-operation or a user mistake. The second data adjusting is done in order to consider the true fuse failures that are not reported, depending mainly of the user and device characteristics.

Based in the experience gained in our country and taking account of a reference more than thirty years old, the values of Table I can be estimated. [2]

For the determination of the Table I values, several factors have been considered, as for example: the cheap fuses are replaced without complains and besides is very popular the custom of replacing the fuse before looking for the fuse operation reason, which normally lead to e new fuse operation. The special fuses are nearly prototypes, then the quality control is not very well established, expecting high failure indexes. In the commissioning test a high number of fuses are operated due to calibration and setting problems.

Table I
Relationship between true faults and complains

Fuse type	Relationship faults / complaints
Distribution, medium voltage (>= 13,2 kV)	3:1
Industrial, medium voltage (<13.2 kV)	1,5:1
Semiconductors application	2,5:1
Distribution, low voltage	6:1
Industrial, low voltage	4:1
Domestic or small industrial, low voltage	20:1
Traction and d.c. applications	2,5:1
Low power applications	10:1
Special fuses and miscellany	3:1
Average Value	5,8:1

From the main Argentinean fuse manufacturer client complain reports during the last ten years, the Table II was filled, taking account of the previously mentioned correction factors.

The true complained fault distribution is as follows:

- Primary 30 %
- Secondary 20 %
- Tertiary 50 %

Non-functional nearly 10 % of the total claims amount (not considered in Table II)
Due to the lack of information, was not possible to relate the failure indexes with the fuse time in service.

CONCLUSION

From this work it is concluded that the general believe that the fuse link is a low reliability device is totally incorrect, due to the yearly and per unit failure range are in the same order of the present circuit breakers.
As general conclusion it is deduced that the yearly and per unit failure index for fuses should be between 0.0002 and 0.002.
The relationship between the complains and true failures are function of the fuse and user types, being in our country 3:1 in average. The true failures without user complains are function of the same factors, being in average 5.8 times the complained ones.
Depending of its importance, the failure distribution is primary 30 %, secondary 20 % and tertiary 50 %. The non-functional faults are 10 % of the whole. The references shown that the number of faults does not increase with the installation time, which seems to be confirmed from this work.
It is deduced that further study on fuse failure and user complain is necessary in order to obtain a more precise fuse reliability index, being the present work a collaboration in such direction.

Table II
Analysis of complains and Fault Indexes, period 1987-1997

Fuse type	Manu-fact-ured (thous)	Comp-lains	True comp-lains	Adjusted Faults per unit year
Distribution, medium voltage (>= 13,2 kV)	25	50	15	0.00018
Industrial medium voltage (<13.2 kV)	15	42	16	0.00016
Semicon-ductor app.	100	72	34	0.00008
Distribution, low voltage	300	350	105	0.00021
Industrial, low voltage	600	655	210	0.00014
Domestic or small industrial, low voltage	80	44	15	0.00037
Traction and d.c. applications	5	12	8	0.00040
Low power applications	25	45	12	0.00048
Special fuses and miscellany	20	14	5	0.00007
Total or average	1.170	1284	420	0.00023

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