# PROTECTION OF A DISTRIBUTION SYSTEM: A WIDE APPLICATION OF ELECTRIC FUSES

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***Abstract***: The distribution system of AEM in Milan (Italy) represents a wide application of fuses. The paper will give the main characteristics and structure of distribution system at 23 kV and 400 V, the purposes and constraints of network protection and some criteria to compare fuses and circuit breakers.

## I. INTRODUCTION

In spite of the increasing use of circuit breakers, electric fuses are largely employed mainly in power system distribution by some electric companies. The paper will deal with the protection against over currents in medium (23 kV) and low (400 V) voltage distribution system used by AEM in Milan (Italy) and in 14 smaller towns of the surrounding area. AEM distribution system is mainly constituted by more than 2.300 electrical substations and a cable net 1700 km long, supplying approximately 25.000 buildings and 400.000 electric users. Both medium voltage and low voltage systems have, under rated conditions, a radial structure so that the protection against over currents must be simple and efficient. The distribution system can be split into typical radial structures which include a transformer supplying some main lines with secondary derivations for users. The protection of this kind of structure is performed only by fuses. This protection system must obtain the following results:

- protection against overloads,
- protections against short circuits,
- selectivity.

The analysis of protection system comparing fuses, circuit breakers and their combination was performed some years ago; recently the chosen solution has been submitted to a revision according to the suggestions of the most recent International Standards. The practical experience of many years confirmed the good result obtained using fuses.

The paper deals with the distribution system, the protection criteria, the comparison between circuit breakers and fuses, the final conclusion.

## II. DISTRIBUTION SYSTEM STRUCTURE

Under normal conditions the distribution system can be subdivided in a lot of circuits having a simple structure like in fig. 1 where it is represented a distribution transformer supplying primary branches who supply final users through secondary branches. Transformer sizes and cable sections have been standardised. In Fig. 1 the most frequent distribution transformer is represented; it has a rated power equal to 400 kVA, it is oil immersed and it has a 4% short circuit impedance. Cable normal sections are also indicated.

The protection system must protect the transformer and cables against over currents (overloads and short circuits) with a satisfactory selectivity.

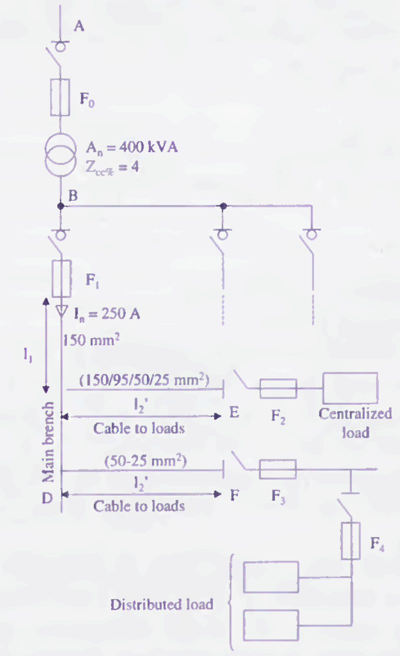


Fig. 1: Typical electrical distribution configuration

### II.1 Transformer protection by fuses

AEM distribution system includes many hundreds of transformers usually oil immersed and, in special cases, dry type ones. Transformer sizes have been standardized and the most popular value is 400 kVA. IEC International Standards show that it is possible to protect these electrical machines avoiding dangerous over temperatures and guaranteeing a satisfactory life duration in [1] and [2]. In fact, because of the difficulty of monitoring all transformer lives trough their loads, AEM protects transformers against overloads by using a simple method which behaves like a thermal image system; it is constituted by temperature sensors which do not allow to overcome hot spot maximum levels and which open substation general switch. According to this limitation no emergency loading capacity is allowed but one doesn't reduce expected transformer life duration and he makes very low fire hazards due to overloads. This simple system works well and transformers have a life duration usually longer than expected values; rare protective interventions occur in few cases due to actual overloads or, more frequently, to poor air cooling conditions during summer hotter months in electrical substation rooms.

Because high voltage cables are protected by main distribution system, high voltage fuses $F_0$ in Fig.1 protect electrical substations against faults occurring inside the transformer or in the connection systems (cables and bus bars) ahead $F_1$. According to [3], high voltage fuses give a satisfactory behavior when they accomplish to some constraints due to the co-ordination with transformer and low voltage fuse-link. The used limits are:

$$I_n \geq 2I_{nt} \quad (1)$$

$$I_{f10} \leq 6\, I_n \quad (2)$$

$$I_{f0.1} \geq 7\, I_n\, (I_n/100)^{0.25} \quad (3)$$

Being:

$I_{nt}$: transformer rated current

$I_n$: fuse rated current

$I_{f10}$: pre-arcing current corresponding to 10 s

$I_{f0.1}$: pre-arcing current corresponding to 0.1 s

An high voltage fuse is also tested near minimum melting current [4] i.e. in the interval 2,7-3,3 $I_n$; so, comparing the minimum predicted fault current with the above value, is verified protection against low fault currents.

Usually low voltage loads are supplied by main branches protected by fuses with rated current approximately equal to 1/2 of the transformer rated current so that high voltage and low voltage fuse characteristics do not intersect in low current values and usually an intersection is found only at a current higher than low voltage maximum short circuit current and their satisfactory co-ordination is obtained.

## II.2 Cable protection by fuses

Fig. 1 shows that a transformer supplies up to 3 branches; each branch is constituted by a copper cable having a stated section (150 mm²) supplying possible secondary branches having section values from 150 to 25 mm². Also loads can be classified as centralized or distributed ones. System protection against over currents is guaranteed by fuses $F_1$ and $F_2$ ensuring :

a) primary branch overload and short-circuit protection,
b) secondary branch overload and short-circuit protection.

Cables rated currents can be evaluated by means of [6]. and overload protection requires to fulfill the well known relations [7]:

$$I_B \leq I_n \leq I_Z \quad (4)$$

$$I_2 \leq 1{,}45\, I_Z \quad (5)$$

Where:

$I_B$ : operating current for which the circuit is designed

$I_Z$: continuous current-carrying capacity of the cable

$I_n$ : nominal current of the protective device

$I_2$: current ensuring effective operation of the protective device.

According to the Italian Standard [8] the current $I_2$ has been substituted by $I_f$ i.e. the operating current in conventional time. As a consequence of (4) and (5) one can protect a cable using:

- a circuit breaker having a maximum rated current In= $I_Z$;
- gG fuses having a maximum rated current equal to $1{,}45/1{,}6\, I_Z = 0{,}9\, I_Z$.

Unfortunately these rules forget that fuses are submitted to a type test intended to verify their "conventional cable overload protection" which control that fuses operate at $1{,}45\, I_Z$ [6].

As far as short-circuit protection is concerned, it is obtained by limiting the Joule integral let-trough by the protection under cable limit value $K^2S^2$.

It is well known that in the case of a single protection against over currents protection is obtained by a device which satisfies conditions (4) and (5) and which has a breaking capacity suitable to the installation point. In the case of fuses breaking capacity is so high that this condition is always verified in a distribution system. In this way, the values of fuse rated current and cable section of the main branch are coordinated for any cable length.

The above condition is not sufficient when lines are made by cables with a decreasing section. In the scheme of Fig. 1, fuse $F_1$ ensures short-circuit protection, fuses F2 and F3 are chosen for overload protection of secondary branches and for short-circuit protection of the supplied circuits. In this case it is necessary to evaluate maximum protected lengths of $l_1$ and $l'_2$.

The worst conditions to analyze is the minimum current in the case of phase to neutral fault. In the example of Fig. 1 short-circuit currents are computed according to [9]; then one compares these minimum currents with fuse characteristics. In order to ensure fuse operation, one must take into consideration fuse gates stated in IEC 60269 [6]. In order to have satisfactory results for any standardized fuse, the fault current must be ≥ $I_{max}(5s)$ that is the value which ensures current interruption in any case; in fact $I_{max}(5s)$ is defined as the maximum value of current for which the pre-arcing time is not more than 5 s that is the worst case for fuses satisfying IEC characteristics gates. The following Table 1 links cable sections and maximum lengths in the example of Fig. 1; in this example $I_{max}(5s)$ is equal to 1.650 A for a fuse rated 250 A.

TABLE 1

| $l_1/S_1$,m/mm² | $F_1$ , A | $l'_2/S_2$ ,m/mm² | $F_2$ , A |
|---|---|---|---|
| Any/150 | 250 | - | - |
| 300/150 | 250 | 25/95 | 200 |
| 150/150 | 250 | 50/50 | 125 |
| 150/25 | 250 | 25/25 | 80 |

These maximum lengths satisfy all practical situations.

## III COMPARISON BETWEEN FUSES AND CIRCUIT-BRAKERS

The usual considerations in the comparison between circuit-breakers and fuses are:

i. fuses are cheaper,
ii. fuses have a very high breaking capacity,
iii. fuses may cause over voltages,
iv. overload protection of cables by fuses produces a 10% reduction of cable current carrying capacity [8] with an increased system cost,
v. fuses produce a single phase interruption,
vi. circuit-breakers allow to open or close circuits through a remote control.

The first two points (i and ii) represent the main advantages. In fact, it was found a cost reduction of 75% in the case of high voltage protections and a reduction of 20% for low voltage installations. Moreover, high breaking capacity allow to avoid any modification in low voltage network when one increases transformer rated power.

Point iii is a weak consideration because standard fuses must limit arc voltage in order to avoid dangerous over voltages [6]. As stated above, some efforts in a better use of existing Standards may allow to remove the limitation in cable current carrying capacity.

The single phase interruption, mentioned in point v, seems a favourable argument because a lot of users are single phase so that some of them will continue to work also after first fuse operation. Finally, distribution systems usually do not use remote control and the point vi doesn't appear very important.

## IV. CONCLUSIONS

In this paper is described a distribution system using only fuses as a protection against over currents. Approximately AEM has installed 10.000 high voltage fuses and 140.000 low voltage ones. Severe acceptance tests are performed in AEM test laboratories.

In many years no critical situation was individuated and no evidence of fuse aging has been observed.


## ACKNOWLEDGEMENTS

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