DISTRIBUTION FUSE LINKS: RESPONSIBLE FOR THE DAMAGE OF EQUIPMENT AT SUBSTATIONS !!!

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ABSTRACT

The main objective of this project is to present the result of studies and tests done on field and in laboratories, with real short circuits, with the purpose of improving the quality of distribution fuse links, specially those used to protect distribution transformers (15 kVA, 45 kVA, 75kVA, 225 kVA, etc). “H” type, in the classes of tensions of 13.8 kV and 34.5 kV.

These protection devices, due to their low quality, were causing several kinds of problems at the distribution circuits, and also at the equipment installed at the Substations. At the distribution circuits, the main problems that occur are that, defects caused at the low-tension circuits (127/220 Volts), such as colliding cables, tree branches at the network, collisions, storms, etc, were causing bi-phased or three-phased short circuits at the feeder circuits of 13.8 kV and 34.5 kV that come from the Substations.

These defects cause many times, the touching of conductors at the side of High Tension, which is detected by the protection equipment installed at the Substations, work done by Re-closer or Circuit Breakers with over current relays.

INTRODUCTION

The distribution system of COPEL was conceived to meet the premises of low initial investment and reduced operational cost. Within this philosophy two distribution tensions were adopted, 13.8 and 34.5 kV the last also being the sub transmission one. The sub transmission lines of 34.5 kV that come from 138/34.5/13.8 kV transmission substations feed 34.5/13.8 kV substations (up to four substations) that attend small localities. The arrangement of these substations allows the installation of up to four 5 to 7 MVA transformers and four 13.8 kV feeders, with the entrance of two sub transmission circuits in 34.5 kV, besides the possibility of installation of capacitor and tension regulator banks. The kind of connection of the power transformers is grounded star at the 34.5 kV side and delta with to-and-fro ground connection at the 13.8 kV side.

The powers of the transformers are 3.75 MVA, 4.2, 5 and 7 MVAs. There are cases of the past of 1.0 MVA, 1.5 MVA, 2.0 MVA and 2.5 MVA, and all of them have taps (34.5/33.75/33.0/32.25/31.5 kV) at the primary side.

Protection at Substations

The 13.8 kV and 34.5 kV exits of the substations are protected by automatic re-closers, with hydraulic, electronic, electro-mechanic and micro processed control, having a tendency to the last ones, that make more precise and small adjustments possible, making the coordination and sensitiveness easier. These re-closers use vacuum, SF6 or isolating oil for interruption, but the last ones are not being used.

Protection at Distribution Lines

With the purpose of improving the reliability and continuation of the supply of electrical energy, automatic re-closers are being used in ramifications that come from the distribution lines in 34.5 kV and feeders of 13.8 kV, coordinated with fuse links and re-closers switches.

HISTORY

Through occurrences survey, we verified the existence of problems related to the protections at the Francisco Beltrão Substation and at other substations of the distribution system of Copel and problems related to collision of conductors at the Distribution Lines of 13.8 kV and 34.5 kV, caused by phase-ground defects throughout these lines and that would be developing to defects between phases, at the spans with problems, and this would cause the stress of the electrical system equipment involved, mainly the transformers of the Substations [2]

Defects at the Low Tension circuits 127/220 Volts, at the secondary of distribution transformers would be causing the burning of the fuse links of the distribution transformers and causing the action of re-closers and circuit breakers at the source substations.

These new tests have the purpose of checking some new solutions proposed to solve the problems that are taking place, among them are:

Tests of new fuse links used to protect distribution transformers, from 4 different manufacturers, three of them are imported and one is national, normal type.

CABRAL test, developed by Copel, device to be installed at the ESV reclosers from Cooper with Resco’s control, with the purpose of making the blockage of the re-closer for short circuits of high currents possible.

Feeders where the tests took place [1]:

- Jacaré feeder – 34.5 kV;
- Enéas Marques feeder – 34.5 kV;
Locales where the tests took place

With the purpose of simulating the short circuits closer to reality, we used the locales where once there were defects at the system.

Location 9 – Pinheirinho circuit 13.8 kV test BT transformer of 112.5 kV

- Test 17
  Short-circuit phase-ground at phase A, breaker switches of the transformer with normal link of 5H.
- Test 18
  Short-circuit phase-ground at phase A, cable on ground, and breaker switches of the transformer with “TYPE A” link of 5H.
- Test 19
  Short-circuit phase-ground at phase A, cable on ground, and breaker switches of the transformer with “TYPE B” link of 5H.
- Test 20
  Short-circuit phase-ground at phase A, cable on ground, and breaker switches of the transformer with “TYPE C” link of 5H.
- Test 21
  Short-circuit phase-phase between the phases A and B, breaker switches of the transformer with normal links.

Location 10 – Pinheirinho circuit 13.8 kV test BT transformer of 75 kVA

- Test 26
  Short-circuit phase-ground at phase A, breaker switches of the transformer with normal link of 5H.
- Test 27
  Short-circuit phase-ground at phase A, cable on ground, and breaker switches of the transformer with “TYPE A” link of 5H.
- Test 28
  Short-circuit phase-ground at phase A, cable on ground, and breaker switches of the transformer with “TYPE B” link of 5H.
- Test 29
  Short-circuit phase-ground at phase A, cable on ground, and breaker switches of the transformer with “TYPE C” link of 5H.

DETAILED STUDIES OF THE INCIDENTS

The Studies of Protection, in theory, were redone, involving the protection equipment of Substations, the Fuse links installed at the derivations and at the protection of Distribution Transformers, concluding that there is no lack of coordination of the protection equipment involved.

Because of this, we decided to check if the problem mentioned above might also occur in other distribution lines and substations, which was verified, according to the answers received from the regional units.

Studies of the Problems

Through the analysis of all the tests of short-circuit realized in field, it was possible to verify that there is the appearance of electrical arch between the breaker switches installed as a protection at the primary of the distribution transformers (13.8 kV and 34.5 kV), when short-circuits happen at the low tension side of these transformers (127/220 V), and when a normal fuse link is used, causing a bi-phase or three-phase short-circuit at the high tension side, which makes the protection equipment installed at the Substations work. Depending on the kind of circuit, this will occur until the circuit is blocked.

This phenomenon is closely related to the Transitory Restoration Tension (TRT).

At the breaker switch, there is the appearance of electrical arch inside its cartridge when the part fuses, in these conditions the breaker switch should extinguish the arch and keep the circuit open.

When the short-circuit current is due to a high impedance fault, the heat emanated by the fusion of the link should decompose the inner part of the cartridge of the link, and then, a gas is formed and it de-ionizes the inner arch. The pressure developed inside the cartridge helps keep the characteristics of open circuit after the arch is extinguished.

The pressure and the recomposing of the dielectrical are related to the size and duration of the defect current.

If during the process of elimination of the short-circuit the tension of the arch breaks the dielectric, it will be re-started, causing the TRT.

If the dielectric is enough to support the TRT, the re-start of the
arch occurs and the short-circuit current will still pass through the breaker switch, even after the cartridge has fallen, until the current passes through the reference again.

**TRANSITORY RESTORATION TENSION**

The distribution systems consist of inductances, capacitances and resistances, that’s why, through the analysis of electrical circuits, we have: [ref 6, 7 and 8]

- The current at a inductor doesn’t change instantly because the tension will be endless, according to the expression bellow:

\[ V(t) = \frac{1}{L} \int_{0}^{t_1} \frac{di}{dt} dt \]  

If \( dt_1 = 0 \), \( V(t_1) = \infty \)

- The tension at a capacitor doesn’t change instantly, because the current will be endless, according to the expression bellow:

\[ i(t) = \int_{0}^{t_1} C \times v(t) \times dt \]  

Analyzing the TRT phenomenon that appears during the interruption of faults, when the breaker switch opens, the short-circuit current will be interrupted and the transitory tension appears between the two terminals of the breaker switches. The equation for the fault current will be given by the equation 3:

\[ icc = \frac{E}{wL} \times [\text{sen}(wt + \theta) - \text{sen}\theta] \]  

The short-circuit current has a continuous component that is proportional to the sine \( \theta \), as shown at picture 2

The transitory restoration tension can be written according to equation 4:

\[ V_{trt} = \frac{E}{\sqrt{LC}} \times [\cos\theta \times \cos \frac{1}{\sqrt{LC}} - \cos(wt - \theta)] \]  

Through mathematic solution, we get to the transitory restoration tension: (equation 5)

\[ V_{trt} = E \times \left[ \cos\theta \times \cos \frac{1}{\sqrt{LC}} - \cos(wt - \theta) \right] \]  

The effect of the resistance at the circuit is absorbing the transitory component of the tension, diminishing the TRT during the opening of the breaker switch when a short-circuit at the low tension occurs. Also at equation 5, the values of \( L \) and \( C \) are from the distribution transformers.

So, to determine the TRT value at the breaker switches, when there are short-circuits at the low-tension side, we should consider the transformer parameters (\( L \) and \( C \)) and the resistance value of the low-tension conductors. Besides the characteristics of the circuits where the defects occur, we also have to consider the quality of the breakers so that there is a complete extinction of the electrical arch during a short-circuit at the low tension.

A bad quality fuse link will take too long to extinguish the arch, allowing the electrical arch to re-start, not interrupting the defects that occur at low tension.

![Figure 2 - Icc Components](image)

**ANALYSIS OF THE RESULTS**

We have done more than 60 real short-circuit tests, in field, at different locations of the system and using 45 kVA, 75 kVA and 112.5 kVA transformers and using 4 kinds of fuse links from different manufacturers.

Through filming and observance of the short-circuits, and also analysis of all the oscillographic values at digital oscillograph, Hioki type, (see oscillographies – annex), we could note and define what kind of link does not generate TRT during a short-circuit at the low-tension network. Consequently it doesn’t cause the electrical arch at the breaker switch for a long time, not ionizing the air around it and not causing short-circuits at
the High Tension side, avoiding the repetitive action of the protections at Substations, and also reducing the stress and the damage of the equipment installed at Substations (specially the power transformers that suffer more efforts).

Comparing the oscillographic values to the observance and analysis of the films, during all the tests, with conventional links and special fuse links (ref.9), we were able to define a maximum time of arch so that its re-start won’t occur at the breaker switch. This maximum time of arch was only possible with fuse links of imported technology. At that time this technology was not available in the country, consequently the costs are much higher than the ones of a conventional link.

These fuse links use vulcanized fiber tubes, which do not present the carbonization that the common paper and fenolite resin links present as they burn during the short-circuit.

The vulcanized fiber contributes to the formation of gas and water vapor during the short-circuit, which is fundamental to avoid the re-start of the arch during the action of the fuse link for low value circuits.

CONCLUSIONS

Through the analysis and verifications of all the oscillographies and films of all short circuit tests, we could rate the parameter found at the distribution systems better; 10 times more than the conventional ones; Through these tests we could change the Technical Specification of Fuse links of Copel, in reference to the tests of type and receipt.

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