SHORT CIRCUIT TESTS FOR DETECTION OF HIGH IMPEDANCE FAULTS

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ABSTRACT

This project presents a summary of the tests realized with equipment, with the purpose of detecting the high impedance faults that occur in the electrical systems, and also the rea...hs of the art of equipment and/or processes used to detect the high impedance faults of the electrical energy distribution system.

During the tests, short circuit tests were made, with normal, aluminum and aluminum with steel soul cables, provoking with same fallen cables over several different kinds of soil, with a great variety of contact resistivity with the soil, also the cases of covered cables were tested, used in compact network, in both 13.8 kV and 34.5 kV, proving that these currents of short circuit of cables fallen to the soil are very small.

INTRODUCTION

High impedance defects in distribution networks are those that occur with low values of short circuit currents, lower than the ones that are possible to be detected by the conventional protection equipment of over current. They are usually caused by contact with branches or broken and fallen cables. The fallen cables that remain energized risk the lives of people that walk on the thoroughfares. They may generate electrical arches in the contact, causing fire if the material that they are resting on is inflammable.

Besides the risk to others, these defects usually cause small harm located at the circuit, and the companies have always neglected to these facts due to the low cost to repair them. That’s why investing in solutions for high impedance faults have never been justified by a conventional cost/benefit analysis.

Even though they don’t cause harm to the circuit, they may generate expenses with reparations to others because of their consequences. That’s why all the searches for a solution to this problem have been motivated by the wish of assuring safety to every one and the prevention of fire.

DISTRIBUTION SYSTEM OF COPEL

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 MVA’s. 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, electromechanic 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.

Meeting

At a meeting in Copel, there was consent about the importance of this research, because evaluations and tests that were done in commercial equipment of which it was expected to get as a product from the detection of high impedance faults not to present satisfactory results. In these tests there were analysis of short circuit involving also compact network cables, both in 13.8 kV and 34.5 kV, proving that these currents of short circuit of cables fallen to the soil are very small.
EXISTING PROTECTION PRACTICES

Existing Protection Against Short Circuits

The system used to identify short circuit events in the distribution networks by electrical energy companies, in general, is the one that uses relays that are sensitive to over currents. This kind of protection is efficient to defects such as network cables contact or internal short circuits in equipment that generate currents of high short circuit in the phases, that is, currents much higher than the maximum currents of charges accepted as normal to each circuit. The phase relays are adjusted to operate above the maximum charge value, turning off the circuit.

Other causes of defects such as contact with branches, loss of current in isolators or equipment, for example, may generate defects with values smaller than the value of the maximum current of charge of the circuit. During some periods of the day the charges may be small and it may occur that even adding the charge current with the defective current, the result won’t be higher than the maximum charge value accepted for the relay, making the identification by the relays of this defective current as phase over current difficult.

To detect this kind of event, another kind of relay is used; one that overlooks the resulting value of the vectorial totality of the phase currents that, in a circuit with no defects and with the equal values of three phase currents, would result in a null value. Unbalance in the phase charges due to the loss of current to the ground when a fall of a cable to the soil occurs, generates a result of the addition of the phase currents different from zero. The overlooking relay of this addition is called neutral or ground current relay, and it is adjusted to operate starting at a certain current value. That’s why the use of the term neutral over current recommended normally are:

\[
0,1 \times I_c \leq I_{neutral} \leq \frac{I_{cc} \times T_{min}}{1,5}
\]

\(I_c\) = charge current

\(I_{neutral}\) = Neutral adjustment current

\(I_{cc} \times T_{min}\) = phase-ground short circuit current minimum at the end of the circuit.

First, we must highlight two important factors that contribute to the appearance of values still found in general companies nowadays for the insensitivity protection band based in relays of neutral for 60 Hz currents.

These factors are:

System Architecture

Connections of the triangle type at the exit of transformers of substations and of the same kind at the primary side of transformers of the network contribute to the unbalance of the charges at the primary phases of the transformer of the Substation, allowing lower values resulting between the phases and, therefore allowing smaller adjustment values on the sensitivity of the neutral relays, with better results on the monitoring of neutral over current to identify faults in the network through sensors. Star Connections grounded at the exit of the substation and star grounded at the network transformers, are too dependent of the balance of charge because it is transferred to the primary of the transformer. At these networks, the balance that comes from charges in consumers with three-phased connection is worse because of the use of mono-phased patterns of network transformers and “MRT” (monofilar with underground way back) networks. These conditions require the use of higher values of relays shots, in a way that avoids interruptions due to the abnormal charge unbalances.

The maximum adjustment values of the protections of neutral over current recommended normally are:

- Until the maximum of 27A for Reclosers - 34.5kV
- Until the maximum of 25A for Reclosers - 13.8kV

This criterion is not always possible to be followed because of characteristics of the existing network and values of charges of the supplied consumers. In this case if it is necessary to use higher values than the ones listed above, they may be used as long as they obey the sensitivity and security criteria, defined by the relation:

\[
0,1 \times I_c \leq I_{neutral} \leq \frac{I_{cc} \times T_{min}}{1,5}
\]

Limits to minimal protection adjustments

Another factor is linked to the limits of the protection equipment that is used in the electrical systems. Working at the distribution systems of several companies we find a variety of models, from equipment controlled by electromechanical, electromechanical re-closers, static, and even the most modern relays, with micro processed controls. At the table 1, there are some examples of equipment and their minimum current of neutral shots adjustment.
TABLE 1 – Neutral adjustment current

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Made by</th>
<th>Type</th>
<th>Adjustment Neutral (A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Recloser</td>
<td>Weco</td>
<td>ESM 800</td>
<td>50</td>
</tr>
<tr>
<td>Recloser</td>
<td>Brush</td>
<td>PMR38</td>
<td>20</td>
</tr>
<tr>
<td>Recloser</td>
<td>McGraw</td>
<td>CXE</td>
<td>12.5</td>
</tr>
<tr>
<td>Recloser</td>
<td>McGraw</td>
<td>KFE</td>
<td>10</td>
</tr>
<tr>
<td>Recloser</td>
<td>Cooper</td>
<td>Nova/F6</td>
<td>1</td>
</tr>
<tr>
<td>Recloser</td>
<td>Whipp</td>
<td>Amazon</td>
<td>1</td>
</tr>
<tr>
<td>Recloser</td>
<td>Brush</td>
<td>Microtrip H</td>
<td>5</td>
</tr>
</tbody>
</table>

More recent equipment have the function SEF – Sensitive Earth Fault, which allows minor adjustments for the ground current with defined adjustment times. It is a function that contributes to reduce the currents of detection of the ground-phase short circuits of lower values, it is not considered as a final solution to this problem.

Operational Procedures in occurrences of high impedance defects

No alarm is activated at the substations or at the systems of automatic supervision when an event with fallen and energized cables that is in conditions that result in a high impedance defect incapable of activating the over current protection occurs. The Distribution Operational Center is only aware of the occurrence when people who are near the locality of the defect notice this fact and reports it via telephone. The operator tries to identify the nature of the fallen cable through questions to the caller, but not always the answers bring certainty.

If there are doubts, due to the risks, the solution that is used is the turning off of the feeder circuit or a switch near the area. This problem occurs due to the pattern of aerial networks. A fallen and energized cable with high impedance contact may be on for minutes or hours.

Copel Procedures to reduce the risks of falling cables

The engineering areas of Copel are up-to-date with the technological evolution that occur in the area of the electrical sector and count with the support of Lactec for studies of research and tests of new protection equipment or new ways that present proposals to improve the sensitiveness of protection of the distribution network. The areas of equipment maintenance of Copel are constantly doing the preventive maintenance of the protection equipment installed in substations and feeder.

Risks of new Network Patterns

One of the patterns that eliminate the problem of cables to the soil, is the pattern of network called underground, where the energized cables are isolated and settled in ducts underground or are buried directly. However, due to the higher cost compared to the cost of aerial networks, they have an insignificant participation in the Brazilian distribution networks.

The Brazilian companies have been using an intermediary pattern named compact network, which is still an aerial network, however it presents characteristics that aim the reduction of interruptions because of contact with trees.

It uses cables covered with full isolation to avoid turning off the circuit by contact with tree branches. It doesn’t have metallic external shield.

The energy cables are hung by isolated fixing spacers that are hung permanently at a steel cable distended between the posts. This technique reduces the aerial space taken by the cables for better coexistence with the arborization and reduction of the trimming area for maintenance, besides allowing the energized cables to be suspended with less pulling traction due to the reduction of the space between the sustentation structure, that is, an average of 3 sustentations added between posts.

Even though the probability of occurrence of cable fallen to the soil is smaller for this kind of network, cases that occur may behave similar to the one with aerial network with uncovered cable (without isolation) where the contact resistance is so high that it works as isolation, not generating current of loss able to be detected.

POSITION OF THE PROBLEM IN BRAZIL

Concessionary Companies

An exchange of experiences realized at the “Subcomite de Operacao e Manutencao do Comite de Distribuicao” – “CODI” (Subcommittee of Operation and Maintenance of the Distribution Committee), in October 1996, nowadays included in the new association of electrical energy companies ABRADEE, evaluated the craft condition about Detection of high impedance faults and of broken cables, with the 16 concessionaries that belonged to the committee on that date. [Ref. 6]
Some highlighted points:
Adoption of minimum values of protection adjustment relays of
ground (neutral), used by the companies, ranged according the
following table:

TABLE 2 – Values of Adjustments of Ground Current

<table>
<thead>
<tr>
<th>Values of Adjustment of Neutral Relay</th>
<th>Number of companies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower than 20A</td>
<td>3</td>
</tr>
<tr>
<td>&gt; than 20A and &lt;30A</td>
<td>2</td>
</tr>
<tr>
<td>&gt; than 30A and &lt;40A</td>
<td>1</td>
</tr>
<tr>
<td>&gt; than 40A and &lt;50A</td>
<td>1</td>
</tr>
<tr>
<td>Higher than 50A</td>
<td>1</td>
</tr>
<tr>
<td>Case with up to 80A</td>
<td>1</td>
</tr>
<tr>
<td>Between 20A and 50A</td>
<td>1</td>
</tr>
<tr>
<td>&gt;10% of the maximum charge</td>
<td>1</td>
</tr>
<tr>
<td>20% of the liberation of charge and 66% of the lower level of short circuit phase/ground minimum calculated with $Z_t=100\ \text{Ohms}$</td>
<td>1</td>
</tr>
<tr>
<td>Maximum 60A for the ground relay circuit breaker / Max 25 Amp for SE re closer</td>
<td>1</td>
</tr>
<tr>
<td>Didn’t answer / didn’t clarify</td>
<td>3</td>
</tr>
</tbody>
</table>

This result shows that the problem does not happen only at Copel. The problem is due to the aerial pattern adopted all over Brazil.
The factors that contribute to the differences of criteria among the companies are the same approached at the item 2.2, as follows:

- There is too much old equipment at the networks which minimal sensitivity adjustments for ground current are high;
- Limitations imposed by the architecture of the electrical system used.

More recent researches

More recent jobs indicate that there isn’t a technology solidified as a definitive solution yet and the research focuses at the search for non-conventional options to identify the high impedance faults.

Evaluation of the Digital Feeder Monitors

Through the Distribution Engineering, Copel has done short circuit tests in distribution networks simulating high impedance defects provoked and observed the equipment at the didactic SE (CDTH) and at Santa Fé feeder at Fazenda Rio Grande Substation.
The results are at reports of the experiments. These tests subsidize some statements that are in this text, that not all the defects will be detected. In these tests, there were indications of parameters of the occurrence when the cable on the soil was of the source side of the network, but not when the cable on the soil was of the charge side.

It was supposed that the error was due to the low potency of the didactic SS, which did not cause significant change of charge to shot triggers of algorithms.
However this condition does not suit with high impedance detection equipment, because cables on the soil in distant or low charge ramifications will also be similar to this condition, and will not generate significant change of charge.

CONCLUSION

The detection of high impedance defects is one of the problems of the electrical system that does not have a solution yet.
The current belief is that there is no technical solution to eliminate 100% of the risks of fallen and energized cables on the soil of public ways.
Energized cables on the soil are a risk of all the aerial distribution systems.
The companies are responsible for actions to control this risk.

REFERENCES