METHODOLOGY TO DESCRIBE HIGH IMPEDANCE FAULTS IN SOLIDLY GROUNDED MV NETWORKS

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ABSTRACT

Progress in power distribution network protection implies new challenges that electrical engineers must deal with. One of these challenges is the detection of High Impedance Faults (HIFs). Overcurrent protection is unsuitable for detecting HIFs in certain conditions. This paper presents an accurate explanation of the HIF detection problem and a method to describe HIFs, using simulation, laboratory tests and fault recordings. The presented study constitutes the basis of a HIF detection method that will be developed in the near future by ULB-Siemens AG.

INTRODUCTION

Protection engineers must cope with new requests of clients. Nowadays, methods to deal with faults that are not detectable by conventional relays are in great demand. High Impedance Faults (HIFs) are one of these complex faults.

HIFs occur when an energized conductor makes contact with a quasi-insulating object or falls on the ground. The main concern regarding HIFs is not the network damage, but the danger for people, animals and property. HIFs involve public security hazard because of the possibility of reaching the fallen conductor, and the risk of fire [4].

The HIF detection difficulty is that, in certain conditions, the fault current is so low that it is undetectable by protection devices. Therefore, a detection method using some magnitudes other than the current amplitude is needed. Detection technology has been commercialized in the last years [2][5][6]. However, their reliability seems not to be satisfactory [4]. Further research is required to develop practical and effective solutions.

This paper presents an explanation of the HIF detection problem and the procedure to describe HIFs, considered as the previous step to develop a HIF detection method.

DESCRIPTION OF THE PROBLEM

The general lack of knowledge of HIFs is the first difficulty for developing a practical detection method. Consequently, the initial stage of our study is aimed to understand and explain the HIF detection problem.

Difficulties of the HIF Detection

The difficulty of HIF detection is related to the situations where faults must be detected using the current amplitude, as the HIF current is especially low [4] (from a few mA up to 70A).

Ground fault detection in solidly grounded systems and systems grounded by low resistor or reactor are based on current monitoring. Therefore, HIF detection in these networks may certainly be a challenge.

The ability of the installed overcurrent ground protection to detect HIFs is determined by the operational zero-sequence current (3I0) in the system under normal operation. In Europe, for instance, most HIF are detected by overcurrent protection since the 3I0 is nearly zero under normal conditions. This is due to the use of three-phase transformers for load supply, which prevents the primary distribution system from being affected by load unbalance [1]. However, American practice of supplying single phase loads by single phase transformers causes that load unbalance affects the primary distribution system [1]. Therefore, a significant 3I0, which can be higher than 100A, is present in the system under normal operation. In these cases, overcurrent relays are unsuitable for HIF detection, since HIF current is lower than normal operation current.

Worst case scenario for the HIF Detection

The distribution network configuration in USA, South and Central America countries, Canada or Australia is highly unfavourable for HIF detection, as it consists of solidly neutral grounded systems that use single phase distribution transformers for single phase load supply. It differs from the common European practise. This explains that the HIF detection technology demand is vastly more important in America than in Europe [4].

We emphasize the need of applying HIF detection methods in distributions systems that use the typical American configuration, where no HIF is detected, implying danger for persons, animals and property.

PROCEDURE TO DESCRIBE HIFS

HIF research is not yet a well known subject. For this reason it is needed to accomplish some stages before being capable of developing a detection method. The three stages of the procedure that we propose to characterize HIFs (represented in figure 1) are:

1) Description of the HIF situation.
2) Study of HIFs while preparing a database, using simulation, laboratory tests and fault recordings.
3) Database analysis and data processing, in order to characterize HIFs and develop a detection algorithm.

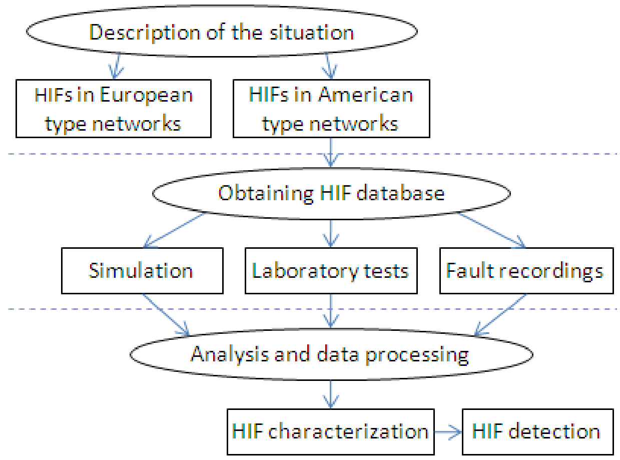

Figure 1: 3-stage procedure suggested to characterize HIF, with the last aim of developing a detection algorithm.

Description of the Situation

The difficulty of the HIF detection problem varies depending on the type of distribution network. The most unfavourable cases, where HIF detection methods are demanded, are distribution systems using the typical American configuration. Once the HIF detection problem is understood, a state-of-the-art study is realized. Our conclusion is that the key point to obtain a practical detection method is following an accurate procedure to characterize HIFs.

Obtaining a HIF Database

Given that HIF is rarely recorded, a simulation model and a laboratory test are developed to obtain the required data. *Iberdrola Distribución Eléctrica SAU* provided us with recordings and information that have been used to validate and complete the present HIF database.

Simulation

We use the simulation program Alternative Transients Program to model HIFs [3] in solidly grounded distribution networks. Our model is constituted by the network components and an estimated HIF resistance.

The considered components of the network are a generator, a saturable power transformer, frequency dependent parameter distribution lines, cables, and saturable current transformers.

The accepted assumptions when designing the HIF model are electrical arc presence and a constant value of the contact surface resistance (*Rcs*). The presence of an arc is expected since the contact between the conductor and the surface is not perfect. The assumption of a constant *Rcs* is a simplification. No dynamic model is able to precisely represent this resistance, as it depends on the variable surface properties. Consequently, the simplification of using a constant resistor of an adequate value must be accepted.

Our HIF model consists of a constant resistance *Rcs* and a non-linear variable resistance *r (t)* representing the arc.

The model is capable of describing the arcing component of a given HIF, by adjusting the model parameters. Nevertheless, in our opinion, the dominant component of HIFs is the variable contact surface resistance, which cannot be modelled or simulated. For that reason, the objective of the simulation is limited to the arc effect study. Experimental tools, such as laboratory test or fault recordings, are needed to prepare the HIF database.

Laboratory Tests

The type of contact surface, the moisture content or the arc length are some of the influencing factors of HIF current. The number of factors is so large, and the relationship between factors and HIF current so complicated, that they can be studied only experimentally. There is no standard to perform HIF tests, so we designed a procedure and adapted the Medium Voltage testing laboratory of Siemens to the requirements of our HIF test.

Tests allow us to observe the influence of the most significant factors on the fault current. Analyzing the results HIF current patterns are determined, making the HIF characterization possible.

Real Fault Recordings

Iberdrola Distribución Eléctrica SAU (Spain) has provided us with some HIF recordings. These recordings allow us to increase the HIF database as well as to validate the laboratory tests.

HIF Characterisation

Studying the database we identify the most distinctive HIF current characteristics: highly dynamic behaviour, waveform asymmetry and presence of arc. HIF current patterns will be described, and analysis techniques will be applied to the currents. The result of the analysis must allow us to decide if the currents fit a HIF current pattern.

LABORATORY TESTS

The decision of performing HIF laboratory tests was made when we concluded that simulation cannot describe some of the main HIF characteristics, such as randomness. A laboratory test design and procedure have been proposed, validated and applied.

Design of the Laboratory Test

The laboratory setup includes all components that are involved in HIFs: an energized conductor, a high impedance contact surface and the ground of the system (see figures 2 and 3). An overcurrent relay and a circuit breaker are used to protect the setup, and a digital fault recorder to record current and voltage.

The test represents a solidly grounded distribution network. The fault is performed in one phase by operating an insulating rod to cause contact between the conductor and the test surface.

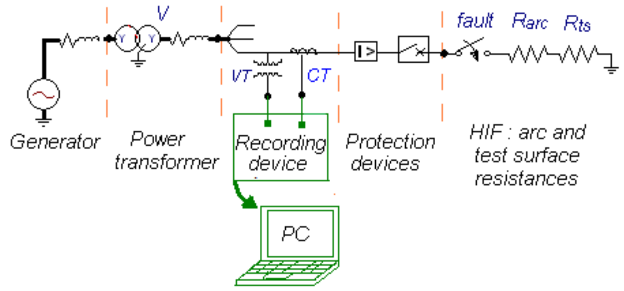

Figure 2: Representation of the setup used to perform HIF laboratory tests.

The fault current depends not only on the contact surface material, but also on the surface moisture, the voltage level or the movement of the conductor.

The test surfaces are made of eleven materials that, in our opinion, are the most usual in HIFs. For security reasons, they are placed in grounded wooden trays. Different surface moisture contents are obtained by watering the surfaces with a spray, simulating the rain. The contact between the conductor and the test surface can be static, placing the conductor to a fixed position on the surface, or dynamic, by slightly moving the conductor over the surface. This movement simulates the oscillating movement of a fallen cable or the effect of the wind. The summary of the tests is shown in Table 1.

Table 1: Summary of the tests indicating the considered influencing factors.

Surface Material	***Test Conditions***		
Sand	Dry/wet	20 kV	Static/moving
Stone	Dry/wet	20 kV	Static/moving
Paving stone and sand	Dry/wet	20 kV	Static/moving
Asphalt	Dry/wet	12/20 kV	Static
Earth	Dry	12/20 kV	Static/moving
Concrete paving stone and sand	Dry	20 kV	Static/moving
Concrete paving stone	Dry/wet	12/20 kV	Static/moving
Tree branches	Outdoor humidity/wet	12/20/36kV	Static
Tree bole	Outdoor humidity/wet	12 kV	Static
Brick and concrete sidewalk	Outdoor humidity	12/20 kV	Static/moving
Reinforced concrete	Outdoor humidity	12 kV	Static/moving

The test procedure is as follows. First, a static test of 7 sec with the dry material is performed. Then, c three dynamic tests of 7 sec are conducted. After that, the test surface is watered and a static test and three dynamic tests are performed. If the static test or the tests with the dry surface show high current or important arcs, the procedure is changed in order to avoid risky situations. In those cases, tests in moving conditions or tests with wet surface will not be performed.

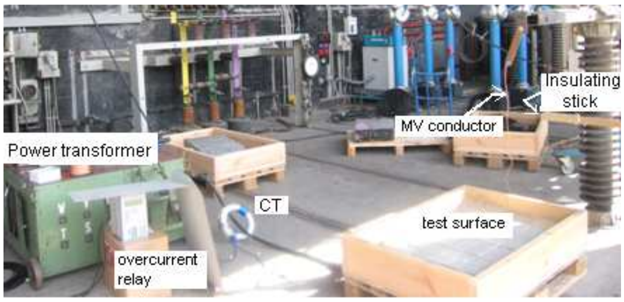

Figure 3: Components of the HIF test laboratory setup.

Performing HIF Tests

As HIF research is not a very developed subject, there is no test standards. Consequently, the test is designed by our research team, and the setup and procedure are validated by performing preliminary tests.

The sand surface is chosen for preliminary tests, since it allows studying influencing factors such as the height of the material and the surface moisture.

The result when testing a sand surface of 10 cm height is a fault with almost no resistance, so the overcurrent relay tripped almost immediately. A second test increasing the height of the sand to 25 cm results in no appreciable recorded current. This was expected because, according to the literature [4], faults on dry sand do not produce noticeable current. A last preliminary test using a 13 cm high wet sand surface causes a perceptible low current of 150 mA, so this is the height used in the sand tests.

After validating the laboratory setup and procedure by realizing preliminary tests, the tests with each surface are performed. The first step is to prepare the surface and to place the conductor on it. Then, after taking the safety measures, the conductor is energized from the control room, and the current and voltage are recorded. Figures 4 and 5 are the recording of the static test with a sidewalk surface.

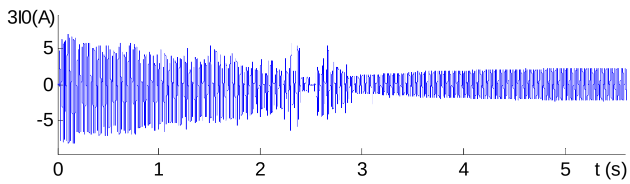

Figure 4: Current of a test with the sidewalk surface, showing the emitted heat and the change of the contact point effects.

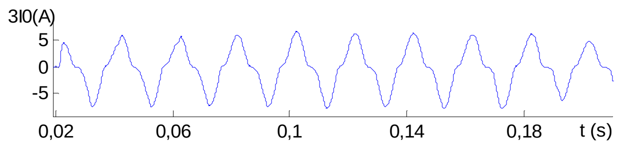

Figure 5: Non-linearity and asymmetry of the current waveform of the static test with a sidewalk surface.

Figure 4 is an example of a highly random HIF current. The first 2.5 sec of the recording can be explained by the effect of the heat emitted during the fault. The heat makes the surface moisture content decrease, and the concrete of the sidewalk surface melt. The effect of this is an increase of the surface resistance, and therefore, a decrease of the current. Then, the contact point changes the position, due to a movement of the conductor or of the arc. This change is observable at second 3, when the current become relatively constant since the properties of the new contact point are more regular. Figure 5 is the starting of the recording shown in figure 4. Non-linearity and asymmetry of the current waveform are the significant observable characteristics.

After the static test we perform three dynamic tests. The end of the conductor is fixed to the hook of the insulating rod, which is handled from the safety area. When the conductor is energized, it is slightly moved over the surface. This causes an intermittent contact, a variable arc length and a changing contact point. This is a common situation in a real HIF that, in general, is not reflected in static tests.

In our opinion, the results of the test are satisfactory and the objectives are accomplished. The recorded current shows the dynamic and random behaviour of HIFs, which cannot be obtained by simulation. Besides that, the influence of the type of surface, the surface moisture, the movement of the conductor and the voltage level can be studied from the recorded current. The analysis of the results allows us to draw conclusions about the different HIF current signature patterns, and also about the characteristics that have to be found in order to identify HIF currents.

DEVELOPING A DETECION METHOD

Developing a HIF detection algorithm involves recognition of the fault and distinction between HIFs and other events.

Recognizing HIFs implies characterizing the fault and finding techniques that make it possible to conclude if a signal presents the HIF characteristics. Therefore, the first step is determining the HIF characteristics based on the literature study [4] and on our database study. Then, analysis techniques for identifying the mentioned current characteristics have to be found. These techniques cannot use the magnitude of the current, since they are aimed at networks where the 3I0 is higher than the HIF current. The functions we propose for analyzing the database are the following:

- Calculation of the change of energy, harmonic amplitude and rms current value.
- Third harmonic current study.
- Study of load change and searching for an indicator of fallen conductor.
- Waveform asymmetry study.

Methods to distinguishing HIF from other events are needed because there are loads, such as arcing welding, that produce zero-sequence currents similar to HIF currents. In order to assure a reliable detection we have to establish a database of these problematic situations, and find a differentiation criterion.

CONCLUSIONS

The general lack of knowledge of HIF is the first difficulty for developing detection methods. This paper presents a procedure to describe HIFs and explains how to design a detection method based on HIF description.

The first step is to describe the present situation, understanding the difficulties for the detection. The worst case scenario is identified as the solidly grounded networks using single phase transformers for single phase load supply (the typical American configuration). In fact, this case is the object of our study. The second step is obtaining a HIF database, constituted by laboratory test results and recordings coming from the network. The database enables us to study the dynamic and random behaviour of HIFs and the effect of the influencing factors in the current signature. The last step is the analysis and data processing of the database. The objective is to identify patterns of the typical HIF currents and to find techniques able to recognize them.

By combining an accurate description of HIF with a distinction criterion to differentiate HIF from other events, an effective HIF detection method could be achieved.

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