RESTORATION OF OVERHEAD DISTRIBUTION NETWORKS BY MEANS OF TEMPORARY FAULT INDICATORS APPLICATION

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ABSTRACT

This paper discusses a new methodology for restoration of overhead distribution networks based on the application of temporary fault indicators. Unlike the traditional fault indicators, these are installed on the network only after the occurrence of the fault. Placed in key points of the network after the disconnection of a feeder, for example, the temporary fault indicators can sense the fault current after the first manual reclosing attempt. Then, they send this information to a portable operation unit that helps to pinpoint the faulty branch of the network by showing the fault´s path in a map. All the devices communicate in a ZigBee mesh network and the fault indicators are georeferenced by GPS, which give their location in the network map.

INTRODUCTION

Due to the large territorial extension in Brazil, some distribution networks have very long rural branches for the energizing of small and punctual loads. Because of economic factors, the investment on reclosers, switches and other protection and switching equipment is very limited, and just few points of the network have these components installed.

In failure conditions with permanent faults, the operation and maintenance crew are called to proceed with the network restoration. In the operation center, the operators analyze the de-energized part of the overhead network and plan what measures can be taken to make the restoration time as short as possible. In this planning, it is considered the traditional restoration methodology [1], known as divide-and-conquer, the crew expertise and the limitations of the network.

Even if the analysis and the planning are efficiently performed, when the occurrences involve long rural branches, the maintenance crew spend much time to check the overhead network looking for the fault site. In some situations, jumpers are opened in order to reduce the portion of the network under analysis and to try the partial restoration of the feeder.

Although there are tools developed to aid this process, as fault indicators (IF), the Brazilian distribution utilities usually do not apply them because of the high purchase and maintenance cost, besides the incidence of vandalism. This high cost is due to the fact that the IFs available in the Brazilian market are not made in Brazil, what makes the final price of these devices excessively high due to the import taxes and the exchange rate between the local currency (real) and the American dollar. Furthermore, the few companies that have IFs operating in their networks often face problems with spare parts, given that even the batteries are expensive and hard to find locally.

The large time spent in the restoration of the distribution system leads to substantial economic losses for the distribution utilities and puts the companies in risk of being harshly penalized by the Brazilian Electricity Regulatory Agency (ANEEL). Moreover, it results in social and economic impacts for those who are served by the distribution utility.

To minimize these undesirable situations, a new methodology has been developed based on the application of temporary fault indicators (TFI). These devices are placed on the overhead network only after the fault occurrence and removed at the end of the restoration process. By switching the opened network on, the TFIs placed on the *fault´s path* are activated and their status are informed to a portable operation unit (POU). In the POU the fault´s path can be visualized and then the fault site can be deduced. It is expected that with the application of this methodology the time necessary to find where the fault is located can be drastically reduced.

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RESTORATION PROCESS

Current Methodology

In order to illustrate how the current methodology is applied by the Brazilian distribution utilities, Figure 1 shows a hypothetical overhead distribution system. In this hypothetic case, a permanent fault takes place and the recloser switches the system off. The restoration process is started by the operation and maintenance crews, that tests the load blocks delimited by the switches in the main feeder.

Theoretically, the tests begin by opening the last switch, isolating the last load block, and trying to re-energize the main feeder. If the network is energized successfully, then it can be concluded that the fault is in this last load block. Otherwise, the procedure is repeated for each block until the main feeder can be re-energized.

However, the blocks to be tested are selected by the operation crew not only by following the procedure described above, but also based on their failure history and the expertise of the operators.

For example, from the Figure 1 it can be observed that the distance between the two normally closed switches (Switch NC) is very high. By the expertise of the operators, the block delimited by the two switches could be split into three smaller blocks if the jumpers are considered. Then, testing these smaller blocks requires cutting the jumpers off and installing new ones, what takes more time than just switching on and off a knife switch.

Proposed Methodology

The proposed methodology aims to shorten the restoration time by installing temporary fault indicators in key points of the already faulted network. In the case of the Figure 1, they could be installed in the same location of the jumpers. Thus, the block delimited by the two last switches would not have to be split into three smaller blocks. Just one re-energization attempt would be enough to evaluate the main feeder of the whole block.

In this case, if the fault is located amid the two TFIs, when the maintenance crew tries to switch the circuit on the fault still would be present. The first TFI would sense the fault current, but the second one would not, meaning the fault would be located between the two TFIs. The fault current sensing, or not, happens in the short time that the recloser takes until opening the circuit again.

The advantages of the TFIs application could be easily visualized in other situations as well. For example, the TFIs could be installed in extensive and problematic branches in some point after the fuse switches, avoiding many fuse links replacements due to re-energizing attempts.

Although the maintenance crew has to install the TFIs on the overhead line, the time spent on it is shorter when compared with the time saved in the restoration process. This is relevant especially in cases where the fault occurs in long rural branches.

To evaluate the proposed methodology a real case was selected from the maintenance recordings of ENERGISA. In this critical occurrence, the maintenance crew managed to totally restore the network in 24h, as it can be seen in a previous paper [2].

The main feeder was composed of three knife switches and two long rural branches that were connected to it by jumpers. In one of these branches the fault took place.

By applying the traditional methodology, the maintenance crew switched the load blocks and, after restoring power to the most of the clients, investigated the two rural branches. These branches demanded the most of the time spent in the restoration.

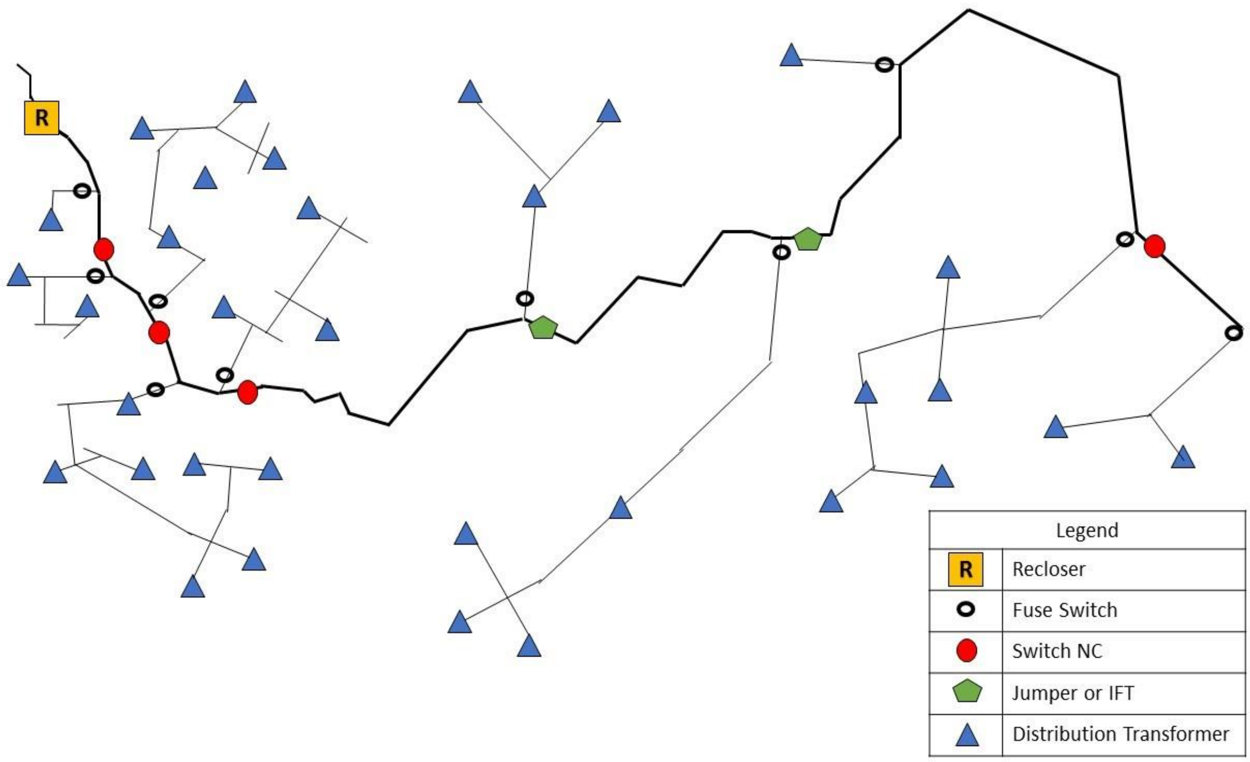

Figure 1: Hypothetic overhead distribution network.

According to a simulation described in that work, if the proposed methodology was applied, the occurrence would be resolved in 65% less time.

DEVELOPMENT OF THE TOOLS

Fault Indication System

The fault indication system is composed of the temporary fault indicators and the portable operation unit, that can be operated alone or connected to a computer.

The TFI´s electronic circuit is composed of the major blocks shown in Figure 2.

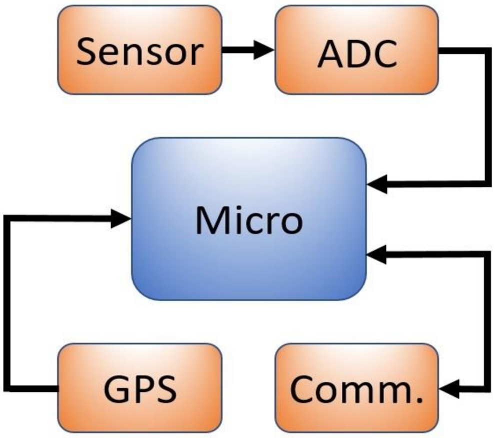

Figure 2: TFI diagram block.

The block named "Sensor" is responsible for the acquisition of the fault current and contains the current sensor itself. Discussed further, the current sensor is placed inside the device used to fix the TFI on the medium voltage cables.

The following block, "ADC", has a low pass analog filter, an amplifier and a 12 bit analog-to-digital converter, which output is connected to the microcontroller circuit ("Micro" block). Once digitalized by this block, the current signal is analyzed by the program running on the microcontroller, that can identify whether the digital information is associated to a fault current or not.

Moreover, the microcontroller receives information from "GPS" block and manage a communication circuit ("Comm. block"). The function of the "GPS" block is to get the coordinates of the TFI from the global positioning system (GPS) satellites. It is based on the GPS module Maestro A2235-H and the obtained coordinates are useful for the portable operation unit to show the fault´s path.

In the last block ("Comm.") are the communication circuits, based on the long-distance ZigBee [3-4] module XBee-PRO 900HP. This module is also applied to the POU and all the devices, TFIs and POU, communicate with each other in a mesh network. Additionally, the TFI has four high-intensity LEDS for local signalling of the fault current.

All the blocks of the TFI, except the "Sensor" block, are condensed in a four-layer printed circuit board (PCB), as shown in Figure 3.

Figure 3: TFI PCB – top and bottom view.

Although the electronic development of the TFI is finished, its body is still under development. On the other hand the POU has the circuits and the body already completed, as shown in the Figure 4.

Figure 4: Portable operation unit (POU).

In addition to be used to operate the fault indication system, the POU is necessary to set up the TFIs. Both can be done through its own interface or by connecting a computer through its USB port. Its interface is composed of a 4x20 alphanumeric display and a membrane keyboard, where the most of the configuration parameters can be set up.

During the operation, a list of the TFIs activated by the fault current is shown on the display, making possible for the operator to deduce the fault´s path and then limit the fault´s search to a specific area. However, when many TFIs are applied it can be difficult for the operator to remember the TFIs positions along the overhead network and mentally visualize the fault´s path.

For these situations, it is recommended to operate the POU connected to a laptop, where a geographical information system (GIS) based software allows the visualization of the TFIs over the distribution network in a map. The information is displayed on the screen similar to a GPS navigation device.

In this step of the research, open source solutions were chosen for software development due to budget limit. For this reason, the operation software was developed for PC (Windows®) and not for a mobile platform as Android® or iOS®. The GIS solution was developed from the OpenStreetMap [5], an openly licensed data base of geographic information that runs in collaborative mode with the users. A free application programming interface (API), the Libosmscout [6], was also used in the development.

Current Sensor

The current sensor developed for the TFI is an association of Rogowski coils manufactured in printed circuit boards. The PCB Rogowski coils [7] are a low-cost solution that fit very well the needs of the present application, where signal distortions and high frequency noises are not critical, unlike in the case of power quality measurements. Consisting in a current transformer with an air core, the Rogowski coil has in its output a low-level voltage signal proportional to the current that flows through the window defined by the following equation:

$$Vrms = M * 4{,}44 * F * Irms\ [V] \quad (1)$$

Where V is the voltage, M is the mutual inductance, F is the frequency and I is the primary current.

As there is no magnetic core, the sensor does not saturate, allowing the measurement of a long range of current values, from the load current to the fault current.

The application of PCBs in the Rogowski coil project allowed the building of an open core sensor, as shown in Figure 5. This solution makes the TFI installation on the overhead line considerably fast and easy when compared with the most of the fault indicators available in the market. In this case, the current sensors, usually traditional current transformers with magnetic cores, have to be split in two or more parts to be integrated to the mechanism used to fix the fault indicator on the medium voltage cable. The sensor shown in Figure 5 consists of an association of four PCB coils in series. This association was necessary to achieve a minimum output signal possible to be used by the TFI electronic circuits. Manufacture in 1,6mm two-layer PCBs, the current sensor has the basic specifications shown in Table 5.

The current sensor will be integrated to the TFI body by an enclosure made of epoxy resin, keeping the "U" shape in order to make the installation easier.

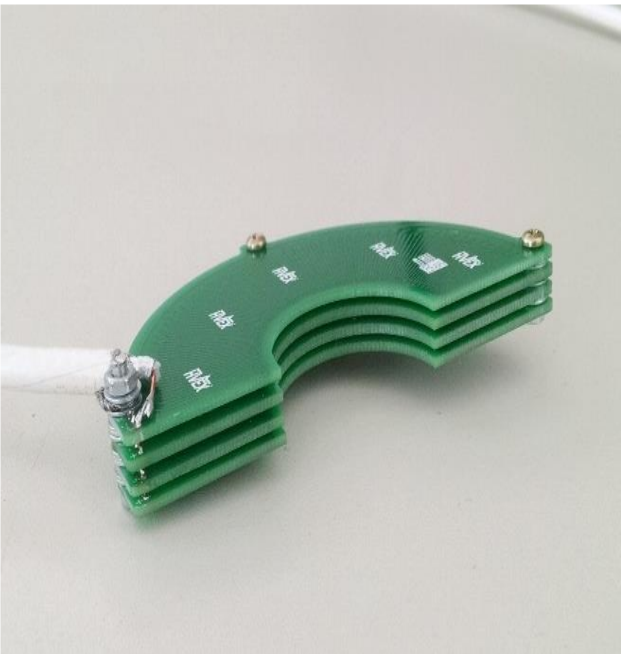

Figure 5: Current sensor.

Table 1: Current sensor specification.

Item	Value	Unit
Frequency	60	Hz
Internal Radius	20	mm
External Radius	40	mm
Number of PCBs	4	
Mutual Inductance	90.80	nH
Number of turns	450	-
Resistence @25°C	115	Ω
Output Voltage	26,6	µV/A

Laboratory and Field Tests

The fault indication system is now under evaluation in laboratory, where all the electronic features are being tested under controlled conditions.

Once the laboratory tests were completed, possible corrections made and when the TFI body was finished, the whole system will be tested in the field. For this, a study has been developed with the sponsor of this research in order to identify critical overhead distribution networks.

Unlike in the laboratory tests, in the field tests it will be possible to assess the performance of the system regarding the communication distance, that is affected by the topology and weather conditions.

CONCLUSION

The simulation of the proposed methodology considering the critical case described before demonstrated that this methodology has a great potential for the Brazilian utilities.

The development of a local solution will delivery to the market a sophisticated, practical and affordable fault indication system that could supply all the Brazilian utilities and companies from other countries with the same needs.

However, the real efficiency of the methodology and the system still has to be evaluated. For this, field tests have to be performed and the results compared with the maintenance recordings of the overhead networks.

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