A Low Harmonic Approach to High Impedance Ground Faults

João M. M. Gaspar Caetano
IST, Technical University of Lisbon
Lisboa, Portugal
zigoerbi@gmail.com

Abstract - In this paper, studies are conducted on the use of Discrete Fourier Transform on the low harmonic content of transients produced by simulated ground faults in distribution networks, for protection purposes. These faults place protection algorithms currently used beyond their operational limits, which is confirmed in this work. Simulations are carried out for a typical 15kV distribution network, where network parameters and fault conditions are changed for a significant number of cases.

Keywords - DFT, high impedance faults, transients, ground fault protection

1 Introduction

It is widely known that detection of high-impedance faults (HIFs) presents still important and unsolved protection problems. Reliable detection and correct discrimination between healthy and faulty feeders is far from trivial when facing a HIF in a medium voltage (MV) network, since phase currents remain almost unchanged and the ground fault current is often very low, frequently below the load current and dependent on both the neutral grounding mode and general network topology, e.g. feeder’s length.

A significant number of protection schemes concerning HIFs have overcurrent time relays (ANSI code 51N) as their central protection algorithm, operating on the general principle that the fundamental component of the zero-sequence current suffers an increase in amplitude when a ground fault is present. In order to work properly, such an algorithm needs some key conditions to be fulfilled: the zero-sequence current in the faulty feeder must be larger than the one on healthy feeders by a safe margin and it must exceed the relay operational threshold. To overcome limitations of overcurrent time relays and add security to the protection scheme, angle information of zero-sequence currents is used in directional ground relays (67N), as well as zero-sequence voltage relays (59N). All these relays operate based on post-fault steady state voltage and current signals; transients induced by ground faults are regarded as noise. It seems consensual that the next step is to find usefulness on transients.

The well known Discrete Fourier Transform (DFT) is the primary phasor estimation algorithm used in almost every protection algorithm against phase-to-ground faults. Looking beyond the fundamental components in the context of DFT, specially those in the vicinity of 50 Hz looks like a valid approach to integrate transients in a protection algorithm [1]. Even though newer signal analysis methods have been recently applied, the purpose of this study is to know how far it is possible to go with the use of DFT in establishing protection guidelines based on transients. Special attention was paid to the minimization of fictitious harmonic content arising from the fact that the moving window applied to the signal will contain at some point in time both pre- and post-fault samples [2].

Faulty networks were simulated using EMTP/ATP, varying fault distance, neutral grounding mode, network topology, fault resistance magnitude, and voltage angle. The arcing characteristics exhibited by some HIFs were also taken into account by means of a non-linear fault resistance. The goal was to find MV network configurations and fault conditions resulting in faults that are out of the functional limits of relays. These multiple configurations and conditions provide a set of cases that allow the conclusion whether a DFT on transients can still detect ground faults and correctly discriminate healthy from faulty feeders.

This work looks at low harmonic content (2nd harmonic) of HIF current transients. According to the results obtained from simulation, this seems a promising approach, which contributes to the methods available today in order to handle HIFs.
2 Simulation

To obtain data for a DFT analysis, EMTP models of 15 kV distribution networks, were used. The network consists of overhead feeders with different sizes and follows a typical radial configuration. All lines were modeled using distributed parameters (J. Marti EMTP/ATP method). The modulated network topology follows the generic guideline: short faulty feeder, long healthy feeders; thus providing more likely conditions to produce failures in the 51N relay.

Simulations were carried using a wide variety of network parameters as shown in Tab. 1. The values of fault resistance were chosen in order to obtain residual line currents, in the range from almost zero to a few dozens amps. As an additional option a dynamic fault resistance was modeled [3] and used to simulate arcing.

<table>
<thead>
<tr>
<th>Fault Distance [km]</th>
<th>{0, 12, 24, 36, 48}</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fault Resistance [Ω]</td>
<td>{263...22780}</td>
</tr>
<tr>
<td>Voltage angle</td>
<td>(\pi/2) (maximum) (\pi) (zero)</td>
</tr>
<tr>
<td>Neutral</td>
<td>(\infty) 12 Ω (R) 12 Ω (X)</td>
</tr>
</tbody>
</table>

Table 1: Possible variations leading to different fault conditions

The DFT analysis was made by means of a moving, one cycle long, time window. A simple transient monitor was also implemented, it functions by comparing phase currents amplitude obtained in the present window, against amplitude values of the last 5 windows; if a residual difference of more than 15 % is found than it considers a transient is present, indicating that a ground fault has possibly occurred. This way one might postpone the harmonic analysis until the window will only contain post-fault samples.

3 Results

Firstly a situation where an actual failure of 51N relay is shown on Fig.1, by looking at the last 3 values of \(R_{def}\) is clearly visible that the \(t_{op}\) values are larger on the faulty feeder, which automatically means that the relay 51N is not going to operate properly.

A possible solution to this particular case lies on Fig.2, where the 2\(^{nd}\) harmonic values presented, are averaged in a time span corresponding to one and a half cycle after the fault instant. An operational threshold of 8% is established, enabling to differentiate the healthy from the faulty feeder.

In this result result it was not considered the use of any transient monitor, so the harmonic content did not exclusively originate from the electromagnetic transient. In fact, the use of the transient monitor invalidates the low harmonic approach, as low frequency components, analysed this way, become insignificant. Thus the use of a transient monitor implies the use of high harmonic content (typically harmonics around 550 Hz).

Another aspect to be taken into account, regarding the use of a transient monitor, is that harmonics analysed this way become overly sensitive to variations in fault conditions. Making it difficult to establish a percentual limit that would enable both the detection of the fault and a correct distinction between healthy and faulty feeders.

![Figure 1: Failure of relay 51N; 12Ω resistive neutral; fault located at 48 Km from substation; linear fault resistance varying from 3kΩ to 22.78kΩ; \(TM = 0.2\); \(I_{op} = 0.5\) A](image)

![Figure 2: One and a half cycle long post-fault 2\(^{nd}\) harmonic comparison between healthy and faulty feeders; 12Ω resistive neutral; fault located at 48 Km from substation; linear fault resistance varying from 3kΩ to 22.78kΩ; values are in percentage of fundamental. A new operational threshold of 8% is established for the faulty feeder.](image)

4 Conclusions

Far better results were obtained by a low harmonic approach, without the utilization of a transient monitor. Operational thresholds established by this method seem to accommodate varying fault conditions. Harmonic content arising from the fact both pre- and post-fault are present, seems this way essen-
tial in obtaining a valid algorithm based on a DFT analysis of transients.

The use of a transient monitor requires the DFT to be centered in higher order harmonics. More important, strong limitations arise from the fact that in this analysis, harmonic’s amplitude tend to have considerable variations with the change of fault conditions, e.g. fault distance.

REFERENCES

