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Methodology for information extraction from oscillograms and its application for high-impedance faults analysis

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ABSTRACT

Safety and quality of supply represent targets that power distribution companies always strive to meet. Among those occurrences that can have simultaneous deleterious effects on both these targets, High-Impedance Faults (HIFs) stand out since the magnitudes of the effects on the system are too small to activate the relevant system protection devices. In this context, the main aim of this article is to present a new mathematical method for analysis of power systems transient events. This technique was used in the pre-processing of signals to help locate and identify Single Line-to-Ground (SLG) faults. The orthogonal component decomposition technique was tested qualitatively with the help of a real fault oscillogram recorded at a power distribution substation. Computer simulations based on a real distribution feeder model were performed and the numerical results showed that decomposition by Orthogonal Components was able to extract information with more than 80% correlation with the fault occurrence, almost 70% for the location and showed great immunity to the fault resistance effect.

Introduction

The efficient identification and location of faults is of crucial importance, since in order to correct a fault, the faulty sector of the system has to be closed down and later, when the fault has been located and corrected, brought back into operation. The power supply must be reestablished in a time compatible with the needs of the consumers affected by the interruption to guarantee the quality of supply. Research activity in this field can be divided into two areas, focusing on the identification and location of faults in electrical power transmission and distribution systems, respectively [1,2]. Due to the great geographical extension of these systems, not only the identification of the fault but also pinpointing its location in the system plays a fundamental role. These topics have appeared in the specialist literature constantly since the initial studies of the 1970s [3,4] and its great relevance is reached in the number of new techniques proposed in academic papers and the optimized methods that have been developed for fault identication and location [5–7].

With regard to transmission systems, research published so far has been not restricted to the generation of theories and models, but has also led to the design and production of fault-locating equipment that is capable of revealing the faulty sector of a transmission line [8–13]. On the other hand, the application of these techniques to Power Distribution Systems (PDS) is still at a very early stage, compared to their use in transmission systems [1,2]. In particular, when conventional techniques are applied to the identication of HIFs in distribution systems, the results tend to be unreliable, as has been pointed out in the specialist literature from 1980 to the present day [14]. The main reasons for difficulties in applying the methods used in transmission systems to distribution systems can thus be summarized [15]:

- Conductor sizes change, thus making impedance calculations nonlinear.
- Multiple feeder taps and laterals.
- Inaccurate models/system data and dynamic configurations can affect results.
- Effects of fault impedance can be significant.
- Less energy to establish clean arcs.
- Evolving fault characteristics and magnitudes can fool a relay's ability to select the correct fault type.
- Small number of measuring points; basically, the observations consist of voltage and current at the substation from which the feeder emerges.
- The presence, on some feeders, of single-phase loads, with the neutral current returning by the ground.

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In light of these problems and in order to contribute to the research area, the objective of this paper is to present a new mathematical approach to the analysis of power systems based on the mathematical technique of decomposition into orthogonal components. The application focused on here is for voltage and current signal processing in order to extract relevant informations about SLG faults in PDS. However, the proposed tool has the potential to be used in several problems related to power systems, mainly for characteristic extractions that can identify the behavior of nonlinear processes.

The original contributions of this methodology presented may be listed as follows:

- The newly developed methodology can be viewed as a signal processing tool for specific use in electric power systems, i.e., the tool will be able to contribute to several problems in electrical systems.
- The decomposition components lie within the time domain and can still be processed by means of other techniques.
- The decomposition is not based on a system of predefined bases. The bases on which the decomposition is performed are determined from the functions to be decomposed, i.e., the decomposition is sensitive to the system's operation.

The article is organized as follows: in Section "High-impedance faults in power distribution systems", some of the main features of HIFs are reviewed and a brief overview of analytical methods is applied to power systems, emphasizing distribution systems undergoing fault. The decomposition of voltage and current in a three-phase power system is discussed in Section "Orthogonal decomposition on three-phase electrical power systems", which also summarizes the technique of orthogonal component decomposition applied to a three-phase system. An oscillogram of a real fault is employed in Section "Qualitative analysis for SLG faults" to demonstrate how the orthogonal components behave in the event of a SLG fault; computer simulations are used in Section "Quantitative analysis for SLG fault" to show how orthogonal component decomposition can be used to analyze power systems suffering faults, by correlating the simulated data with the parameters of HIFs; final conclusions are drawn in Section "Conclusions".

High-impedance faults in power distribution systems

High-impedance faults are asymmetric short circuits, usually phase to ground, which produce currents too small to be detected by conventional techniques and, consequently, incapable of triggering relays or fuses [4]. In other words, the identification of HIFs is a task for which analysis of the amplitudes of voltage and current in the system is quite inadequate. Consequently, current research in the field of fault identication and location focuses on extracting features that may help in this task from the transitory behavior of the voltage and current waveforms. For example, in [16–20], the undervoltage behavior at the moment when the SLG fault occurs is employed to estimate its location, as it is evident that measurements made in the steady state of the system (following the fault) would be insufficient for this task.

This very complexity and the importance of finding a solution to this problem are reflected in the large number and the diversity of techniques proposed in the literature dedicated to this question. However, before citing examples of such studies, it would be useful to know that the analysis of an electrical power system can be broken down into different situations, as followed [21]:

- Transient or steady-state analysis.
- Normal working or fault condition data.
- Balanced or unbalanced systems.

The available methods used to locate faults in power systems can be classified along the lines outlined above; some of these are based on electrical circuit analysis. An outstanding example of these methods was presented in [22] and designed to locate faults occurring either in single-phase systems or, in its generalized form, in three-phase systems, calculating the distance to the site of a fault by estimating the magnitude of the voltage along the feeder. In [23,24], a similar approach is followed in other proposals based on estimates of the current and voltage at each node of the feeder, but with refinements that make these methods especially suitable in particular cases. More recently, an algorithm was proposed in [25] based on [22] although adapted to make it more suitable for radial distribution systems.

Among the methods based on analyzing the steady states of moments before and after faults, those that estimate system impedance are prominent as proposed in [26,23,24,27,28,25,29,30]. Techniques are based on impedance estimation date from the beginning of the 1980s [31] and they have remained the subject of research until the present day, now being integrated into more recent approaches [32–34]. Broadly speaking, intensive use is made of signal-processing tools to extract as many characteristics as possible from the voltage and current waveforms, with the aim of locating the fault. For example, in [35] the analysis of voltage and current signals at multiple frequencies enables the possible places where the fault occurred to be listed, in a way that demonstrates the great refinement of these consolidated methods.

Another possible way to analyze an electrical system with respect to a fault occurrence consists of studying the dynamic behavior of the voltage and current waveforms. This approach can be implemented using a number of different techniques; briefly, these may be grouped as follows:

- Statistical analysis [36–38].
- Methods using traveling-waves theory [39–41].
- Frequency-domain decomposition [32–34,42].
- Wavelet decomposition [1,5,43,44].

The techniques based on the principle of traveling waves are different from those based on impedance because they do not make use of the fundamental components of voltage and current at the time the fault occurs. Rather, the site of the fault is located by exploiting the electromagnetic waves reflected and transmitted in the faulty system. The use of signal processing techniques for the extraction of characteristics that are attractive for the identification of HIFs is one of the main motivators in Wavelet transform-based approaches. In [43], Wavelet coefficients are used jointly with other tools for the extraction of characteristics. Characteristics extracted by means of signal processing tools, as the Wavelet transform may be defined, are frequently associated with intelligent systems as in [45].

Artificial Intelligent computational systems, especially those involving artificial neural networks and fuzzy logic [46–49,29,50,51,15,52], receive great attention in view of the inbuilt ability of these systems to map the relationship between the inputs and outputs of typical nonlinear processes. Such tools are generally employed to analyze processes in which these input–output relationships are not well-known, making them an attractive choice for the task of identifying and locating faults. Thus, the tasks to be performed when a HIF occurs become better assisted by means of automated systems. In [53] a learning technique was employed to estimate the zone of the distribution system where a HIF occurred.

Even though there is a great variety of approaches to the problem of identifying and locating HIFs, it is still possible to extract from these approaches a common model for the solution of both