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Modeling and detection of high impedance faults

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ABSTRACT

High impedance faults are difficult to detect by conventional overcurrent relays mainly because of their low current magnitudes. This paper describes a model for representing high impedance faults in electrical distribution systems. The model is based in a non-linear resistance representing the high impedance path during this kind of faults. Based on this model, the performance of several electric variables associated to high impedance faults is analyzed and an algorithm for high impedance fault detection in electrical distribution systems is presented. Field measurement and computer simulations validate the high impedance fault model and the proposed fault detection algorithm.

Introduction

High impedance fault (HIF) detection represents a real challenge to protection engineers in electric utilities because of the complexity and variability of the phenomena involved. HIFs have the characteristic of producing low current magnitudes compared to nominal load currents, which makes difficult its detection by conventional overcurrent relays in a reliable way [1,2]. Some additional features that influence HIF detection are weather conditions, fault conditions, fault distance, short-circuit rate, conductor type, etc. There exist many causes leading to HIFs in Electrical Distribution Systems (EDS). For example, a HIF may occur when an energized conductor makes contact with the soil surface without a solid grounding, or when the conductor get in touch with a branch tree or any other object representing a high impedance path to ground. Under these circumstances, the relatively high voltages close to human beings and the electric arc associated to HIFs represents a serious risk to public safety and a major concern on industrial installations.

HIFs are closely related to the grounding method used in EDS. A description of these methods can be found in [3]. In México, North America and Latin American countries the common practice is to use a solidly grounding system. This approach facilitates the setting of conventional overcurrent relays for detecting low impedance faults. Typical fault levels at the distribution substations bus are 5–6 kA, 1.5 kA at the end of the feeder and load currents in the range 300–500 A. Since typically a HIF produce currents smaller than 75 A, these events are difficult to detect even for conventional ground relay with settings in the range 200–300 A. A complete description of the current profile along a typical distribution feeder is presented in [4].

The problem of HIF detection has long been recognized by the industry and several techniques have been proposed in the literature. In 1988, Huang et al. evaluated the performance of four different algorithms for HIF detection using a staged fault test [5]. The evaluations were done off-line and the results demonstrated that, under certain circumstances, some algorithms perform better than others. Latter, in the 90s, Emmanuel et al. carried out extensive measurements of harmonic currents at a “staged ground impedance fault in sandy soil”. The aim was to assess to what extent harmonic currents can be used for HIF detection [6]. In 1997, Zori et al. [7] developed an algorithm for arcing fault detection using the bus voltages and the odd harmonics.

The above developments were followed in 2004 by Stoupis et al. [8], who presented an algorithm based on the Discrete Wavelet Transform (DWT), higher order statistics and an Artificial Neural Network (ANN) in order to detect HIFs in medium voltage networks. Latter, Hou presented a HIF detection algorithm based on the sum of current differences using a one cycle difference filter [9]. In 2006, Adamiak et al. [10] applied expert systems and pattern recognition techniques to calculate harmonic energy levels during HIFs.

In 2007, Elkalashy et al. used the DWT to analyze arc reignitions associated to high impedance faults caused by leaning trees [11]. The low current magnitudes observed and the periodicity of arc reignitions makes the DWT a suitable tool to analyze this kind of phenomena with good accuracy. In 2011, Baqui et al. also used

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the DWT and ANNs for HIF detection in distribution feeders. In this approach, changes in current waveforms caused by HIFs and normal switching events were also considered [12]. The obtained results validate the effectiveness of the proposed methodology to discriminate HIFs from switching transients.

In 2012, Samantaray proposed an ensemble decision tree which provides effective decision on HIF detection [13]. This approach also used extended Kalman filters to analyze the harmonic content in the current signals and feed a classifier based on random forest techniques. Good results for HIF detection in large distribution systems are reported by the author. Recently, Bakar et al. [14] proposed a method to detect and locate HIFs based on the DWT, where the fault characteristics are extracted from voltage measurements and then compared with a database obtained from computer simulations They also apply rank analysis to locate the likely faulted section.

A key aspect in the development of a HIF detection algorithm is the need of accurate models for representing HIFs. One of the first models for representing HIFs in EDS was proposed by Emmanuel et al. in [6]. The HIF was represented by means of two DC sources interconnected by two diodes in order to obtain the non-linear characteristics of voltage and current (v–i). In [15], this model was improved by adding two resistances and inductances between the diodes. Latter, Nam et al. [16] proposed a new model to simulate HIFs by means of two time dependent series resistances. The combined action of both resistances allows representing HIFs with good accuracy. Latter, Elkalashy et al. [17] proposed a HIF model based in two components: an arc model and a resistance.

The main contribution of this paper is the development of a general purpose model for representing HIFs of varied characteristics in EDS based in a single non-linear resistance. A second contribution is the development of an algorithm for HIF detection in EDS. In order to achieve these objectives, the paper has been organized as follows: in the second section, the results of several field tests are presented. Based on these measurements, in the third section a model for representing HIFs is proposed. The model is based in calculating a non-linear resistance representing the high impedance path associated to the fault. This section also includes a methodology for calculating the model parameters. In the fourth section, an algorithm for HIF detection in EDS is presented and tested. Finally, the paper conclusions are drawn. It should be mention that the HIF model and the HIF detection algorithm were implemented in the MODELS section of the Alternative Transient Program (ATP) [18] for validation purposes.

Measurements of high impedance faults

The first step in the development of a model for representing HIFs in EDS is to measure currents and voltages during this kind of events. Field measurements provide reliable information about HIF behavior, which would be useful for understanding the dynamic of the phenomena involved and also laid the basis for further model development.

Twenty field tests were carried out in a 13.8 kV, ≈8 miles (12.8 km) long distribution feeder owned by the national utility of México (CFE). All the measurements were carried out during a sunny day in the dry season using a sampling frequency of 20 kHz. The HIFs were simulated at the end of the feeder by means of a fallen conductor over the soil surface covered by dry grass. Bare and cover conductors representative of those used in Mexico (3/0) were used during testing. Current and voltages were measured on site and the different data files were recorded using the Common Transient Data Exchange (COMTRADE) protocol, in order to be available for further processing in ATP.

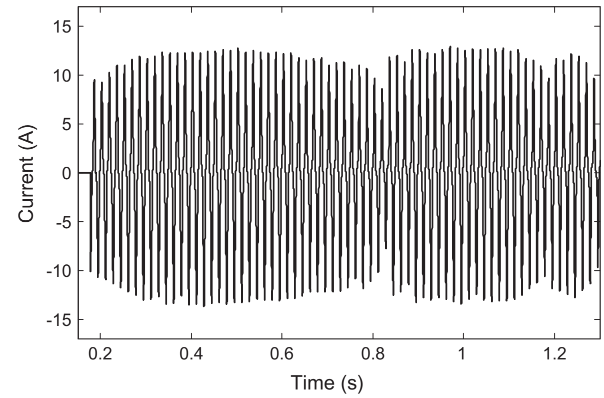

Fig. 1. HIF current for a bare conductor.

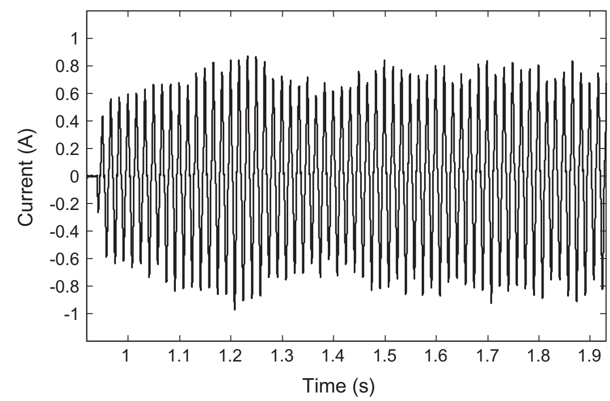

Fig. 2. HIF current for a cover conductor.

Figs. 1 and 2 show typical current measurements for bare and cover conductors during HIFs respectively. For all the tests carried out in bare conductors, there was a variability in the peak current magnitudes in the range 7–15 A_{peak}, the mean value is 9.8366 and the standard deviation is 0.1440.

For cover conductor the variability in all the tests is in the range 0.25–1 A_{peak}, the mean value is 0.675 A. and the standard deviation is 0.0721. As expected, cover conductors represents a higher impedance to fault currents because of the insulation sheat, meaning smaller currents magnitudes during HIFs. The oscillograms presented in these figures share many HIF features also reported by other authors [6,16,17,19]. It should be mention that during the

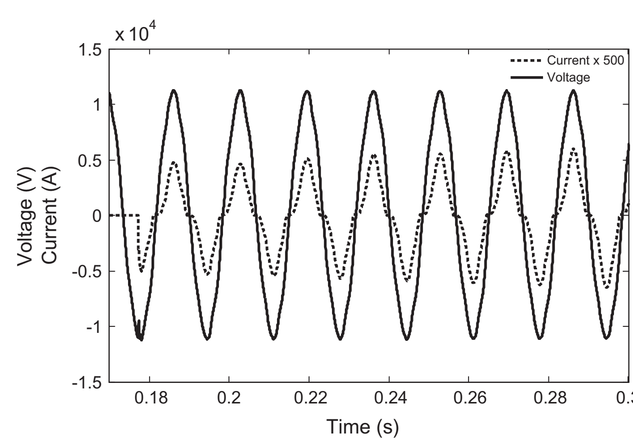

Fig. 3. Voltage and current during a HIF for bare conductors.