SYSTEM FOR DETECTION OF HIGH IMPEDANCE FAULT

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ABSTRACT

High impedance faults result when an energized primary conductor comes in contact with a semi-insulated object. In general, high impedance faults are associated with arcing at the point of contact. These high impedance faults present a serious public safety hazard and a risk of fires. High impedance fault detection has been a major concern of protection engineers for a long time. This paper discusses a system for detection of high impedance fault that has been implemented in an IED for feeder protection. The paper also discusses laboratory tests and field tests at different utilities.

INTRODUCTION

Electric power systems have grown rapidly over the last fifty years. This has resulted in a large increase of the number of lines in operation and their total length. These lines experience faults for many reasons. Most of these faults are ground faults. Conventional protection systems based on overcurrent, impedance, or other principles are suitable for detecting relatively low impedance faults, which have a relatively large fault current. These conventional methods have been used with success for a long time to detect low impedance faults for and to take necessary action to isolate the faulted section of the system.

However, a small percentage of the ground faults have a very large impedance. They are comparable to load impedance and consequently have very little fault current. These high impedance faults do not pose imminent danger to power system equipment. However, they are a considerable threat to humans and properties. The IEEE Power System Relaying Committee working group on High Impedance Fault Detection Technology [1] defines High Impedance Faults as those that 'do not produce enough fault current to be detectable by conventional overcurrent relays or fuses'. Protection engineers and researchers have been challenged for a long time to develop a suitable technique that will detect high impedance faults with a reasonable degree of reliability, while being secure against false detection.

BC Hydro and Powertech Labs Inc. tested three high impedance fault detection systems [2]. The most significant result was that the higher frequencies of high impedance fault signatures played an important role in high impedance fault detection and in distinguishing high impedance faults from other types of faults or normal arcing operations. In another high impedance fault detection study [3], experience with high impedance fault detection and testing is summarized, and the formal evaluation of the performance of a randomness based high impedance fault detection algorithm is discussed.

Some other attempts to detect high impedance faults have been published. They are reported in some of the references provided in this paper. It can be appreciated that conventional means for detecting high impedance faults in electrical power lines are typically not reliable. Therefore, a need exists for a new reliable and economic solution for detecting high impedance faults in electrical power lines which addresses the ramifications of detecting and determining what to do once a high impedance fault is detected.

This paper describes a new high impedance fault detection system and results from laboratory and field test results. The high impedance fault detection system uses some of the techniques discussed in [4-7]. Some of the field test results can be found in [8].

HIF DETECTION SYSTEM

The work presented in this paper relates to a new system for high impedance fault detection that includes a multi-algorithm approach. Each algorithm uses various features of phase and/or ground currents to detect a high impedance fault. Suitable features of the currents include their waveform signatures, their sample values etc. Fig. 1 shows a schematic diagram of an electrical power system having a high impedance fault detection system *HIF Detect*^{TM}. Also shown in Fig. 1 are the potential transformer PT and the current transformer CT which provide the analog inputs for the high impedance fault detection system.

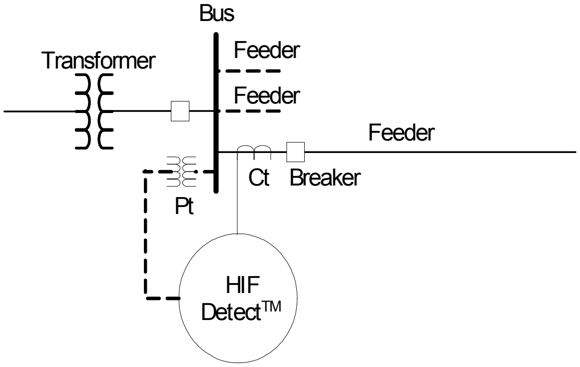

Fig. 1. Electrical power system having high impedance fault detection system.

The high impedance fault detection system, *HIF Detect*^{TM}, is based on some of the techniques discussed in references [4-7]. The individual high impedance fault detection techniques have different algorithms for detecting high impedance faults. The individual high impedance fault detection algorithms can each have a different confidence level. A fault is identified as a high impedance fault once it is detected independently by the algorithms and processed through decision logic.

As shown in Fig. 2, power system signals are acquired, filtered, and then processed by individual high impedance fault detection algorithm. The results of these individual algorithms are further processed by a detection logic to provide the detection decision. The detection logic can be modified depending on the application requirement.

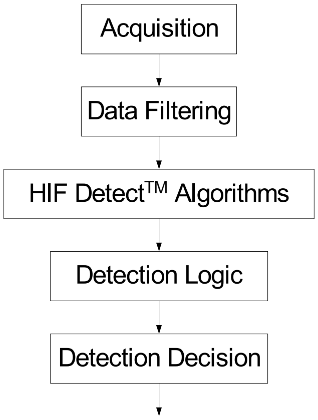

Fig. 2. High impedance fault detection system.

The high impedance fault detection system reported in this paper is based on algorithms that use current signatures in all of the 3-phases and/or ground which are considered non stationary, temporally varying, and of various burst duration. All harmonic and non-harmonic components within the available data window can play a vital role in the high impedance fault detection. One challenge is to develop a data model that acknowledges that high impedance faults could take place at any time within the observation window of the signal and could be delayed randomly and attenuated substantially. The model is motivated by previous research, actual experimental observations in the laboratory, and what traditionally represents an accurate depiction of a non stationary signal with a time dependent spectrum.

The high impedance fault detection problem addressed in the development is formulated as such:

$$\text{Hypothesis } H_0 : s(t) = l(t) + n(t) \tag{1}$$

$$\text{Hypothesis } H_a : s(t) = l(t) + n(t) + f(t) \tag{2}$$

Where s(t) represents the monitored phase and/or ground currents. It is assumed that all measurements are corrupted with additive Gaussian noise n(t). The high impedance fault signature is denoted by f(t) and represents the instantaneous value of the fault current. Normal load signals are denoted by l(t). Hypothesis H_0 represents a non fault situation and Hypothesis H_a represents a high impedance fault situation.

TEST RESULTS

High impedance fault detection system was developed with research and development effort conducted over seven years. HIF algorithms were first tested in the laboratory which was followed by field testing.

Laboratory Testing

Fig. 3 shows in simplified form the laboratory setup that was developed to experimentally stage high impedance faults and to collect data for testing and evaluation. The setup included two 120V/4500V, 1 kVA transformers connected in parallel and energized from a 120 V, 15 A, 60 Hz power source. A bare conductor was connected to one terminal of the transformer secondary to simulate a downed conductor. The other secondary terminal was connected to a copper plate buried in soil, thereby simulating the ground electrode and the earth.

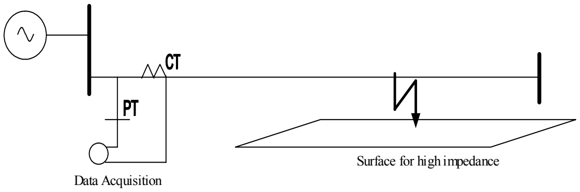

Fig. 3. Laboratory setup for collection of HIF data.

The bare conductor was dropped on a variety of soil surfaces to investigate differences in the resulting currents. The current signatures were collected using a data acquisition system based on the National Instruments data acquisition and signal conditioning boards with LabVIEW software. The data was sampled at 20 kHz, quantized to 14 bits, and stored in binary format. Each test case had a duration of 50 seconds.

Fifteen cases were run for seven different wet surface conditions (wet and frozen sod, soil, asphalt, gravel, sand, and concrete) for a total of 105 high impedance fault cases. This data acquisition scheme was also used to collect signatures for currents for single-phase nonlinear loads (e.g., a TV, a fluorescent lamp, a PC, a bridge rectifier, a phase-controlled motor drive, and an arc welder). A total of 22 load files were created.

High impedance fault detection algorithms have been extensively tested between 1998 and 2000 using data generated at the laboratory. Test results are very encouraging. Detection rates are around 80% while the false operation is close to 0%.

Field Testing

The laboratory results encouraged ABB to implement the techniques in an embedded platform so that HIF detection can be integrated into IEDs (Intelligent Electronic Device) used for protection and control of feeders. Additional HIF field data was obtained in 2002 from a research laboratory that independently performed HIF testing in a distribution system. The implemented HIF detection system required adaptation and modification to perform satisfactorily both with laboratory data and acquired field data.

Once satisfied with the performance of the implemented HIF algorithms, with laboratory and acquired field data, ABB approached several utilities to verify the performance of the HIF detection system and collect HIF data with staged-fault testing. Many utilities responded to the request positively and successfully conducted field testing.

In addition to the IEDs equipped with the HIF detection system *HIF Detect*^{TM}, a separate data acquisition system for the collection of field data from staged HIF testing was also developed as shown in Fig. 4. This has been done to collect data from the field testing that is independent of the HIF detection units for future use and replay of the fault events. The data acquisition system is based on National Instruments LabVIEW software using the off-the-shelf Data Acquisition System (DAS) card and other hardware from National Instruments. Assembly of the data collection system and development of the software for the system was done at ABB.

Fig. 4. *HIF Detect*^{TM} equipped IEDs and data collection system.

Field testing of IEDs equipped with high impedance fault detection system *HIF Detect*^{TM} was done in the process of collecting data from staged HIF testing – these field tests took place six times between January and December 2004 at various locations. Photographs of some of the staged-fault testing on various surfaces are shown in Fig. 5 through Fig. 9.

Fig. 5. Validation of *HIF Detect*^{TM} on gravel.

Fig. 6. Validation of *HIF Detect*^{TM} on sand.

Fig. 7. Validation of *HIF Detect*^{TM} on concrete.

Fig. 8. Validation of *HIF Detect*^{TM} on soil.

Fig. 9. Validation of *HIF Detect*^{TM} on grass.

Results of field tests were very encouraging. High impedance fault detection system, *HIF Detect*^{TM} , could successfully detect HIF on gravel, sand, concrete, soil and grass. The *HIF Detect*^{TM} also proved to be very secure when presented with various load conditions that resemble HIF situations.

ABB decided to implement the *HIF Detect*^{TM} as a standard feature in its state-of-the-art IED REF550, released in January 2005. The *HIF Detect*^{TM} is also implemented in the next generation IEDs; such as REF 615 and REF 630. One of the hallmarks of the HIF detection system is its user-friendly design. There are only two settings. The user can select the level of security in the HIF detection system with a very intuitive setting called HIF level, which can be set anywhere between 1 and 10 in steps of 1, 10 being more secure than 1. The default setting is 5. The other setting is related to the grounding system – the user can select between an ungrounded and grounded system and also has a choice to disable the feature. Field testing of the commercially available unit is continuing.

CONCLUSION

The electric utility must always have public safety as a top priority. The utilities need an economic solution and a system that can reliably detect high impedance faults, and are also secure in that they do not falsely detect a high impedance fault. High Impedance Fault (HIF) detection requires a different approach than that for conventional low impedance faults. Reliable detection of HIF provides safety to humans and animals. HIF detection can also prevent fire and minimize property damage. Innovative technology for high impedance fault detection is available and discussed. Results of many successful field tests indicate that the developed technology works as expected.

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