Ground alert

Reliable detection of high-impedance faults caused by downed conductors

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With more than one million miles of overhead power lines crisscrossing the country, the USA is especially vulnerable to a certain kind of hazard – downed conductors. Straddling different climatic zones and topographies, the lines are exposed to all kinds of conditions, normal and abnormal. A severe incident can bring conductors crashing to the ground where, if still energized, they pose a danger to human life and the environment. Utility engineers clearly need to be able to quickly detect and repair a fallen line. However, to do so they first must reliably identify and analyze faults that are caused when the conductors make contact with the ground. Unfortunately, there is a problem when the fallen line creates a high-impedance fault (HIF): If the line falls onto soil, asphalt or foliage, the fault current is so low that conventional protection devices are unable to detect it.

A relay recently developed by ABB solves this problem by means of new detection algorithms. Each algorithm can trip the relay independently, but it is also possible to make tripping dependent on multiple indication of a fault.

Downed or open conductors are potentially life-threatening. If the lines remain energized, human contact can result in serious injury or worse. Arcing can also start fires. On top of this, if the downed conductor is detected by a relay and that relay trips a circuit-breaker in a substation, power for vital public services may be lost. Operation of hospitals, airports and traffic control systems could be jeopardized as a result. It is this potential seriousness of downed lines that explains the efforts utilities have made over the years to find a reliable method of detecting them.

A problem with high-impedance faults is that they tend to exhibit not only low fault currents but also random behavior.

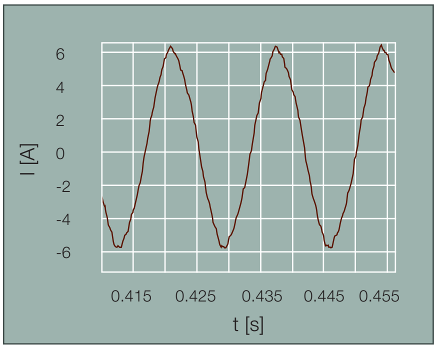
The problem with trade-offs

A high-impedance fault occurs in the event of a still-energized conductor making unwanted electrical contact with the ground. Many different types of surface are imaginable: a road surface, sidewalk, tree limb, and so on. What all these surfaces have in common is that they reduce the flow of current toward the fault point to a level that cannot be reliably detected by conventional overcurrent protection schemes. Typical HIF currents on a distribution system can range anywhere from zero amperes for contact with asphalt and dry sand to 50 A for contact with wet grass or 75 A for contact with reinforced concrete.

The nature of HIFs has been studied in detail since the early 1970s in the hope of finding a practical method of detecting such disturbances. Utility protection engineers and researchers have investigated and tested several solutions, and several different techniques for detecting HIFs have been developed over the years. A problem, however, is that HIFs tend to exhibit not only low fault currents but also random behavior, with unstable and wide fluctuations in current level. The fault signals are also rich in harmonics and have high-frequency components 1. Most of the research into HIFs has focused on developing sensitive but reliable fault detectors. The methods developed make use of, among other things, sequence components, neural networks, communication schemes, and/or harmonic analysis.

An additional problem is that not all HIFs can be detected, regardless of which method is used. For example, if a conductor near the end of a feeder falls to the ground, very little fault current flows and very little load is lost, making it difficult to detect the event. This case serves to show that it is practically impossible to detect all HIFs and achieve high security against ‘false’ trips. (‘False’ trips occur when the relay thinks an HIF condition exists, but it is actually due to another, different disturbance somewhere in the system.) Also, while communication schemes are extremely useful for detecting the loss of potential on a distribution line, they tend to be anything other than cost-effective.

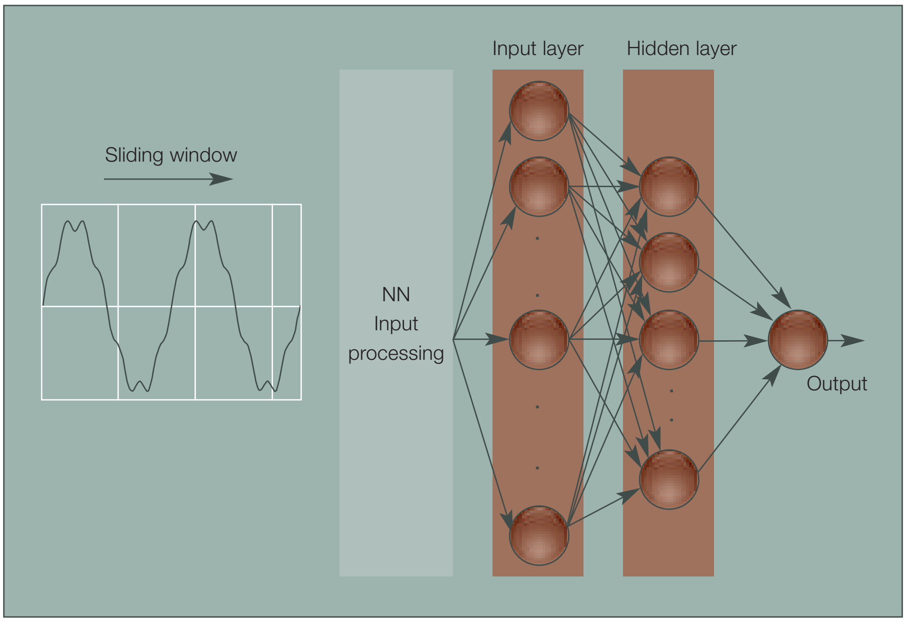
1 Typical high-impedance fault current waveform



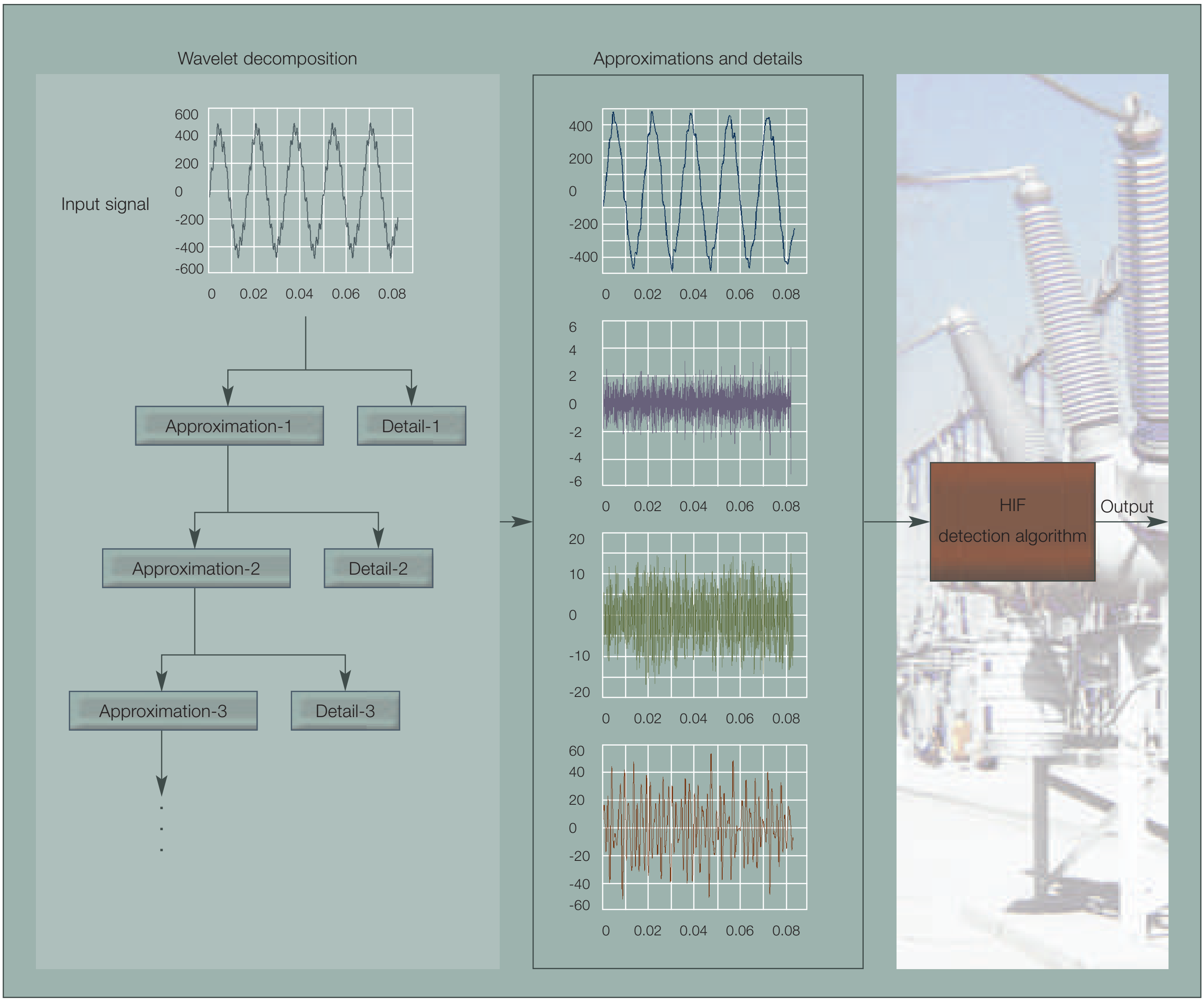
Given these problems, it has seemed virtually impossible in the past to devise a perfect system for detecting HIFs.

The utility protection engineer must consider all the trade-offs involved when deciding how to apply HIF detection. It may not be practical, for example, to trip the circuit immediately – the consequences of disabling traffic lights, elevators, heating systems, life support equipment, etc, must all be considered. Instead, rather than trip the circuit, the protection engineer may elect to relay an alarm. In this case, the general public is warned of the danger and service

2 The neural network algorithm



3 The wavelet algorithm, implemented by ABB in a distribution relay to detect high-impedance faults



personnel are dispatched to search for the downed line. If, on the other hand, the method of detection is able to distinguish between HIFs on a main feeder line and on a feeder lateral, a utility may go for a trip when the main line is affected but only an alarm if the HIF is on the laterals. Which of these is chosen – trip or alarm – will depend on the consequences in each case.

Detection algorithms

Relay vendors have developed several HIF detection products in the past, but with limited success. Products based on communication schemes have proven to be too costly, while those based on relay detection algorithms did not meet expectations. In recent years, work on HIF detection at Lafayette College¹⁾ in the USA has produced new algorithms in the area of artificial intelligence: neural networks, wavelets and higher order statistics. These were also later tested using MATLAB.

Neural network algorithm

The neural network algorithm developed for HIF detection is a two-layer network **2**, trained using back-propagation with an adaptive learning rate. The data used to train the network came from tests conducted at Lafayette College. After lowpass filtering, a three-cycle window of data was normalized to unity before being used as input. The target outputs for training were set to one for HIF and zero for non-HIF.

Wavelet algorithm

The wavelet algorithm is based on multi-resolution analysis of recorded

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[1] Development work on the HIF detection algorithms at Lafayette College was carried out under Prof. Ismail Jouny.

current loads via discrete wavelet transform 3. This algorithm delivers a description of load currents as they change with respect to time at different scales, where large scales are associated with low-frequency components and small scales are associated with high-frequency signatures. The wavelet transform decomposes the current signal into little wavelets that are localized both in time and frequency, and are all scaled and dilated replicas of the same mother wavelet.

Higher-order statistics algorithm

The higher-order statistics algorithm is based on the higher order spectra, namely the bispectrum and trispectrum, which are by definition the two-dimensional and three-dimensional Fourier transform of the third and fourth order cumulants. This algorithm is influenced by the non-stationary features of HIF currents, their skewed statistics (especially at high frequencies), and their non-normality or lack of resemblance to white noise. The detector was developed such that a detection decision is made either using only the second-order statistics of the current values, or using third- and fourth-order statistics of the current values at an additional stage. The basic concept here is: Given a set of data and a fixed false alarm rate (or probability of false detection), what is the achievable detection decision assuming accessibility to second-, third-, and fourth-order statistics of the data?

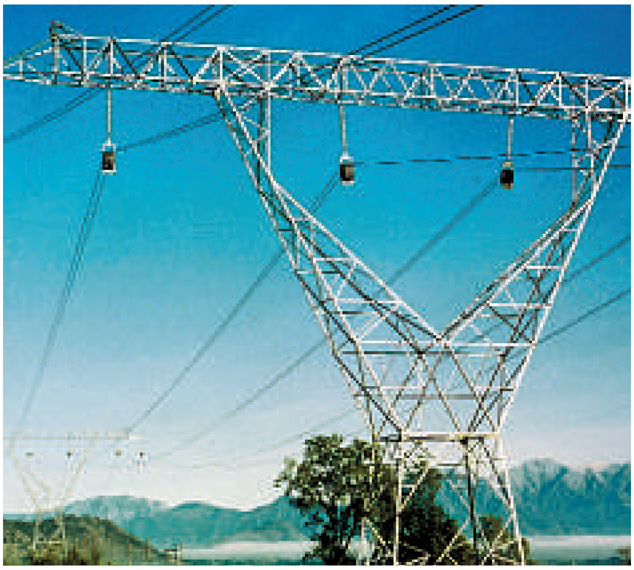
> Tests have shown that detection of high-impedance faults with an ABB relay using the new algorithms is close to 100 %.

Close to 100 percent HIF detection

ABB collaborated with Lafayette College in testing and implementing the detection algorithms that were developed. Before any of these algorithms could be implemented in a distribution protection relay, however, it first had to be determined what the optimal sampling rate and window size would have to be for data analysis. It was found that a window size in the order of seconds was adequate for proper HIF detection and also that effective detection is achieved with a sampling rate of 32 samples per cycle. The decision was then taken to implement the wavelet and statistics algorithms in ABB's new distribution protection relay, which, fittingly, has a sampling rate of 32 samples per cycle.

It was also imperative to have new field data with which to test the algorithms. ABB was able to obtain from the Canadian Electrical Association (CEA) HIF field data that included high-impedance fault and load-current signals as well as results of tests in which conductors were dropped on different surfaces. Using this new data, ABB was able to optimize the algorithms for detection of these disturbances.

Test results with the new data show that the algorithms operate effectively and with good reliability. Detection of high-impedance faults with the relay using this data is close to 100 %, with a false alarm rate of approximately 8 %.



Vote of confidence

The design of the new distribution relay permits later implementation of the neural network as a third algorithm, either operating as an independent detection mechanism or in a 'voting configuration'. This feature would be a significant market differentiator, especially in the USA, where the potential for such protection is expected to be greatest and the benefits for the power companies most significant.

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[3] **I. Jouny, S. Kaprielian:** High impedance fault detection. Lafayette College, Electrical Engineering Department.