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# High Impedance Fault Detection on Distribution Systems

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Craig G. Wester
Member, IEEE
GE Power Management
20 Technology Parkway, Suite 330
Norcross, GA 30092 USA

*Abstract* - **The detection of high impedance faults on electrical distribution systems has been one of the most persistent and difficult problems facing the electric utility industry. Recent advances in digital technology have enabled practical solutions for the detection of a high percentage of these previously undetectable faults. This paper will review several mechanical and electrical methods of detecting high impedance faults. The issues and application of this technology will also be discussed.**

## I. INTRODUCTION

A high impedance fault (HIF) results when an energized primary conductor comes in contact with a quasi-insulating object such as a tree, structure or equipment, or falls to the ground. The significance of these previously undetectable faults is that they represent a serious public safety hazard as well as a risk of arcing ignition of fires.

A high impedance fault is characterized by having an impedance sufficiently high that it is not detected by conventional overcurrent protection, such as fuses and overcurrent relays. Unlike low impedance short circuits, which involve relatively large fault currents and are readily detectable by conventional overcurrent protection, these HIFs represent little threat of damage to power system equipment. High impedance faults produce current levels in the 0 to 50 ampere range. Typically, an HIF exhibits arcing and flashing at the point of contact.

Throughout the utility industry, there has been differences of opinion on how often HIFs occur. Normally, utilities do not keep good records on the number of down conductor instances. It is seldom recorded on trouble reports unless it results in a fuse or breaker operation. While it is likely that only a few percent (5-20%) of all distribution faults are high impedance faults, means exist to detect a high percentage of HIFs.

## II. MECHANICAL DETECTION METHODS

One type of mechanical HIF detection method consists of a device(s) mounted to a cross arm or pole. A unit is mounted under each phase wire. It provides a low impedance ground fault by catching the falling conductor. The force of the falling conductor releases an internal spring that ejects a bus bar to make contact with the fallen wire and create a ground fault. The ground fault created will cause conventional overcurrent protection to operate. Sagging conductors that do not come in contact with earth or a grounded object could be detected by this mechanical method. The installation and maintenance costs are high. For bi-directional coverage, six units would have to be mounted on each pole. Even though the cost may be high to allow usage on every pole, utilities may install in certain areas, such as churches, schools, or hospitals.

Another type of mechanical HIF detection method uses a pendulum mounted aluminum rod with hooked ends. It is suspended from an under-built neutral conductor. The falling conductor is caught and produces a low impedance ground fault, which operates conventional overcurrent protection. Typically, two units are mounted per span. Sagging conductors that do not come in contact with earth or a grounded object could be detected by this mechanical method. Ice, wind, and tree growth could cause a false detection.

## III. ELECTRICAL DETECTION METHODS

### *A. High Impedance Fault Analysis System*

This electrical HIF detection method measures the third harmonic current phase angle with respect to the fundamental voltage. There is a distinct phasor relationship between the third harmonic current and the faulted phase voltage. The device calculates and stores the average ambient third harmonic current phasor. When a fault occurs, the new third harmonic current phasor is vectorially subtracted from the stored value. A high impedance fault is issued if the magnitude is above setting and angle matches a predetermined value for a down conductor. The device acquires current and voltage values from the relaying current and voltage transformers. Typically, one unit is installed in each distribution breaker. Units have been in service since the early 1990's.

### *B. Open Conductor Detection*

This electrical HIF detection method detects loss of voltage to determine a broken conductor. The system measures the voltage at each end of a single phase lateral. When the voltage of any phase drops below the specified threshold, a transmitter sends a signal on the neutral conductor to a receiver at the upstream device. The upstream device opens if voltage is present at the upstream device. Systems have been under test since 1992.

*C. Digital Feeder Monitor*

The digital feeder monitor is based on the high impedance fault detection technology developed at Texas A&M University after more than a decade of research, funded in part by the Electric Power Research Institute. The digital feeder monitor uses a high waveform sampling rate (32 samples/cycle) for the ac current inputs in conjunction with a high-performance (RISC) microprocessor to obtain the frequency response required for arcing fault detection. Expert system techniques are employed to assure security while maintaining dependability. The device is intended to be applied at a distribution substation to monitor one feeder. Units have been under test at over 60 electric utilities throughout the country since 1992. The high impedance detection technology has been incorporated into a complete relay system with conventional overcurrent protection, reclosing and metering functions.

The device incorporates nine sophisticated high impedance algorithms with an expert arc detector (EAD). High impedance fault detection only requires inputs from the three phase and ground currents via relaying current transformers. Voltage inputs provide supplemental phase identification and are not required for down conductor detection.

The basis for down conductor detection is sequence dependent. Distinction between an arcing intact conductor and an arcing downed conductor is determined by looking at patterns in the load current at the beginning of the fault. When a conductor breaks, generally there is a loss of load or an overcurrent condition when a conductor falls across another phase or a neutral conductor and then falls to the ground. User settings determine what constitutes a loss of load or an overcurrent condition indicating that the conductor broke. To determine if the conductor has now fallen to the ground or hit a grounded object, the detection method looks for persistent arcing. A downed conductor is indicated only when a loss of load or an overcurrent condition precedes detection of persistent arcing.

If there is only arcing and no loss of load or an overcurrent condition preceding the arcing detection, arcing detected will be indicated and not a downed conductor. It is assumed that the line is intact, even if arcing is present. This may be an indication of a bad insulator or an intact conductor. A broken conductor at the end of the line will produce no loss of load and would be declared as an arcing conductor.

Arcing causes bursts of energy to register throughout the frequency spectrum of the currents. These arcing bursts have some distinct qualities and signatures and several of the high impedance algorithms are used to detect these patterns. The odd, even and non-harmonic components of the phase and neutral currents are analyzed for these patterns. Algorithms look for energy and randomness patterns in the currents when the conductor is arcing. Individual outputs of the arc detection algorithms are inputted into the expert arc detector.

The purpose of the expert arc detector algorithm is to assimilate the outputs of the basic arc detection algorithms into one cumulative arc confidence level per phase. There are actually 24 independent basic arc detection algorithms, since both the energy and randomness algorithms are run for the odd, even and non-harmonics for each phase current and for the neutral current. An arc confidence level is determined for each phase and neutral. The expert arc detector algorithm compares the cumulative arc confidence level values or high EAD counts to the user's arc sensitivity setting.

For the device to be secure and dependable, the expert arc detector must determine there is arcing multiple times. The number of times is dependent on the arc sensitivity setting. This setting determines how many times it must be determined that the conductor is arcing and to what level (or threshold) does the device have to determine the conductor is arcing. To allow coordination with conventional overcurrent protection, the output contacts are not permitted to operate for a user defined time to allow the conventional overcurrent relays or fuses to operate. Due to the security and dependability measures taken, a decision on the down conductor is reached in approximately 0.5-5 minutes.

Settings exist to block the device's operation for a high rate-of-change of current and a three-phase current event. An extremely high rate of change is not characteristic of most high impedance faults and is more indicative of a breaker closing, causing associated inrush. Since this type of inrush current causes substantial variations in the harmonics used by the high impedance algorithms, these algorithms ignore all data for several seconds following a high-rate-of-change event that exceeds the associated rate-of-change threshold, in order to give the power system a chance to stabilize. Starting a very large load on a feeder often has many of the same effects as the closing of a breaker. Starting a large motor, for example, involves three phase current inrush that the high impedance detection method will sense, and this inrush typically will be rich in certain harmonics. The high impedance detection algorithms ignore the data generated by a large three-phase event.

If the device determines that a downed conductor or arcing exists, it attempts to determine the phase on which the high impedance fault condition exists in a hierarchical manner. First, if a significant loss of load triggered the arc detection algorithms, and if there was a significant loss on only one phase, that phase is identified. If there was not a single phase loss of load, and if an overcurrent condition on only one phase triggered the algorithm, that phase is identified. If both of these tests fail to identify the phase, the phase with a significantly higher confidence level (e.g. higher than the other two phases by at least 25%) is identified. Finally, if none of these tests provides phase identification, the device analyzes the correlation between the peak portion of the voltage waveform with the neutral arc bursts. If there is correlation with a particular phase voltage, that phase is identified. If that test fails, the phase is not identified.

Conductors that do not continuously arc, but have time periods between arcs can be detected by the arcing suspected identifier algorithm. For example, if arcing is caused by a tree limb contact or insulator degradation, arcing will typically be present intermittently with relatively long periods of inactivity. In such cases, arcing may be affected by such factors as the motion of a tree limb or the moisture and contamination on an insulator. The purpose of the arcing suspected identifier algorithm is to detect multiple, sporadic arcing events. If taken individually, such events are not sufficient to warrant an arcing alarm. When taken cumulatively, however, these events do warrant an alarm to system operators, so that the cause of the arcing can be investigated. The user can select the number of maximum number of arcs and an acceptable period of time. Due to the possible long periods of arcing inactivity, a HIF decision could be reached in minutes to hours.

Tests to date indicate the device can detect approximately 80% of arcing conductors. Not all faults can be detected, because not all surfaces produce arcing. Without arcing, the device is unable to declare a down conductor decision.

## IV. Typical Fault Currents for HIFs

Table I provides typical fault current levels for different surface material. [1] Downed conductors on dry asphalt or dry sand may not be detected, since both surfaces may not produce arcing. On the other hand, reinforced concrete provides the most arcing.

TABLE I
TYPICAL FAULT CURRENTS

| Surface | Current (A) |
|---|---|
| Dry asphalt | 0 |
| Dry sand | 0 |
| Concrete (non-reinforced) | 0 |
| Wet sand | 15 |
| Dry sod | 20 |
| Dry grass | 25 |
| Wet sod | 40 |
| Wet grass | 50 |
| Concrete (reinforced) | 75 |

## V. Implementation Issues

### *A. Contrast in Detection Goals*

There is a contrast in the detection goals of overcurrent protection versus high impedance fault detection. Overcurrent faults provide sufficient current to be detected by conventional protection, while HIFs exhibit very low current levels. Excessive current for too long may damage equipment and overcurrent protection is used to detect these abnormal conditions. Safety or hazard and fire prevention are the primary goals of high impedance fault detection rather than equipment damage. The inability to detect high impedance faults can cost utilities millions of dollars through liability and customer service issues.

### *B. Electrical and Mechanical Detection Options*

Several mechanical and electrical detection options were described. Typically, the electrical devices described are applied one per feeder and the mechanical devices applied in certain areas to protect against falling and sagging conductors, such as schools and churches. The electrical detection methods prove to be the least expensive to install and maintain, but not all HIFs are detectable, since several surfaces and even a broken conductor at the end of a feeder will not cause changes in the electrical parameters measured.

### *C. Customer Service*

High service factor or customer service/continuity is a priority within the utility industry due to increasing competition. HIFs have the potential to cause service interruptions and deliver substandard power to users. Presently, a HIF remains undetected until someone sees the broken conductor or arcing line and reports the problem to the utility company. Applying electrical detection methods allow utilities to respond faster to down conductor occurrences. For example, it will take a customer longer than a few minutes to contact the utility and with a HIF detector applied the conductor could be detected and de-energized quickly. Operating times of the electrical HIF detectors are within a few minute time frame, which to a protection engineer seems to be an eternity, but utilities must realize that the response of a HIF detector is much faster that waiting to receive a customer complaint call. Regardless of which HIF detector is applied, accurate, dependable and secure operation is very important. Some utilities have created response procedures that incorporate the output of the HIF detector and a customer complaint call when a down conductor is detected by one of the previously described electrical detection methods.

HIF detectors that include conventional overcurrent protection, reclosing and metering can provide a complete fault detection system that could detect approximately 95-98% of all faults (low & high impedance) on a distribution system (assuming that 10% of the faults are down conductors that can be detected 80% of the time).

### D. Feeder Selection

Ideally, it would be best if utilities installed HIF detectors on all distribution feeders at once. It is unreasonable to apply HIF detection on every feeder due to the economics, but utilities can develop a planned or phased installation. The circuits to be considered for HIF detection could be based on those circuits with past HIF events, population dense circuits, fire prone areas, older circuits with undersized conductors, 4 to 35kV circuits, overhead construction and ungrounded and grounded systems. Underground distribution circuits pose less of a public safety concern.

### E. Trip or Alarm

The most critical decision to be made after installation of high impedance fault detection is what control actions to take if a HIF is detected. There is no one method for determining which control action a utility should take. Each utility will have to determine a control strategy to fit their goals. However, it will be important to carefully document decisions and reasonings. No high impedance detector or overcurrent device can protect from initial contact. There is agreement within the utility industry that if a down conductor is present, one would not want to reclose (automatically or manually) after detection of the HIF. An example implementation strategy for the high impedance logic which many utilities could follow is shown in Table II. [2]

It may not be appropriate to trip a circuit under all conditions given the presence of a down conductor. Some circuits may be feeding critical loads in dense suburban areas, such as hospitals, industrial processes and traffic signals. If a feeder is not tripped or patrol action initiated for a downed conductor, possible personal injury, legal liability, or property damage may occur. But if a feeder is unnecessarily tripped, possible traffic hazards, medial emergencies and service interruption may result. The high impedance detector could be configured by the utility for different output logic, as well as sensitivity thresholds, to optimize the HIF detector to a given feeder.

TABLE II
EXAMPLE OF DETECTOR LOGIC

| Arcing | Load Loss | Overcurrent | Decision |
|---|---|---|---|
| N | N | N | Normal |
| N | N | Y | Overcurrent * |
| N | Y | Y | Overcurrent * |
| Y | N | N | Alarm - arcing |
| Y | N | Y | Trip - down wire |
| Y | Y | N | Trip - down wire |
| Y | Y | Y | Trip - down wire |

* - trip by conventional protection

Those electrical HIF detectors that sense arcing could be set to alarm for arcing conductors due to tree growth, insulator failure, arrester failure or distribution transformer arcing.

### F. Communications

Depending on the installation of HIF detectors, utilities have to review the communication path that will report the detection of an occurrence from one of the electrical HIF detectors. If SCADA (System Control and Data Acquisition) communication is available, the HIF can operate an output contact to report an occurrence. Several electric cooperatives and municipals do not have SCADA systems, but could use a simple auto-dialer alarm system via a conventional phone line or the HIF detector could be configured to automatically trip the feeder breaker.

### G. Potential for Litigation

Down conductor accidents have been and will be the subject of litigation. There is much controversy regarding the litigation issues of applying HIF detectors. However, most liability insurance professionals, attorneys and most utility executives would agree that the problem will not disappear by ignoring it. Most feel that the utilities will be in a better position, regarding liability issues, if they are to show a proactive approach to solving the high impedance fault detection problem. This approach will reduce the overall risk to person or property, although the risk will not be entirely eliminated because not all down conductors can be detected. Most liability cases against utilities settle out of court, however, the settlements typically range in millions of dollars.

### H. Reliability

In today's society, secure and dependable detection is required for high impedance fault detectors. Early solutions, like the electromechanical product which detected changes in 3Io current, proved to not be very secure and often caused nuisance trips. Several of today's electrical HIF detectors have been installed on utility systems to verify the secure performance of the HIF detector under normal system conditions, such as noisy feeders, arc furnaces, arc welders, capacitor switching, line switching and load tap changing. Many utilities have performed their own stage fault tests on both grounded and ungrounded distribution systems. Some utilities have performed "drop" tests, where a line is intentionally dropped to test the operation of the HIF detector.

## VI. Conclusions

The introduction of the microprocessor has made the technology possible to detect a high percentage of previously undetected high impedance faults. Field tests have proven that many of the HIF detectors are secure and reliable. Utilities must ask themselves whether they want to be proactive or reactive in applying HIF detectors, now that proven technology is available and affordable.

## VII. References


[1] "Detection of Downed Conductors on Utility Distribution Systems", IEEE PES Tutorial Course 90EH0310-3-PWR, 1989.

[2] B.M. Aucoin, R.H. Jones, "High Impedance Fault Implementation Issues", *IEEE Transactions on Power Delivery*, January 1996, Volume 11, Number 1, pp 139-148.

**GE Power Management**

215 Anderson Avenue
Markham, Ontario
Canada L6E 1B3
Tel: (905) 294-6222
Fax: (905) 201-2098
www.GEindustrial.com/pm