HIGH IMPEDANCE FAULT DETECTION

by

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ABSTRACT

The results of Electric Power Research Institute projects RP1285-1, 1285-2 and 1285-3 are discussed. In RP1285-1 a method for analyzing the positive, negative and zero sequence currents of the fundamental and third and fifth harmonics was developed. The currents are monitored continuously and changes in the statistical distribution are used to identify faults. In RP1285-2, detectors based on third harmonic current phase shift and magnitude were developed. In RP1285-3, a detector based on radio noise generated by a high impedance fault was developed. Both types of detectors were built and field tested with encouraging results, but both have their limitations.

HIGH IMPEDANCE FAULT DETECTION

INTRODUCTION

A fault that cannot be recognized and cleared by conventional overcurrent protective devices is frequently called a "high-impedance" fault. As Figure 1 shows, the fault current can be substantial, and yet be considered a high impedance fault. The same magnitude fault in Figure 2 would not be a high impedance fault because the fuse would blow. However, any fault drawing current of less than about 100 amperes would fall into the category of the high impedance classification. Thus, fault impedance alone cannot be used to define a high impedance fault because the load current and protective device rating have some bearing on the magnitude of a fault that can be recognized and cleared.

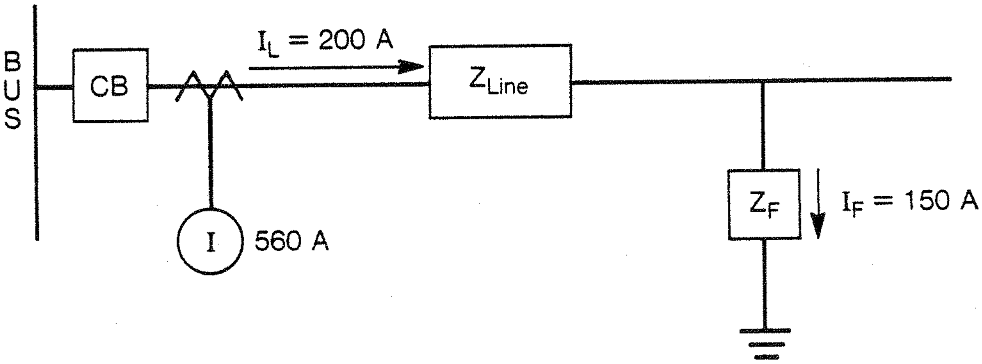

Figure 1. A "high impedance" fault. The overcurrent relay, set to pick up at 560A, will not operate for a 150A fault.

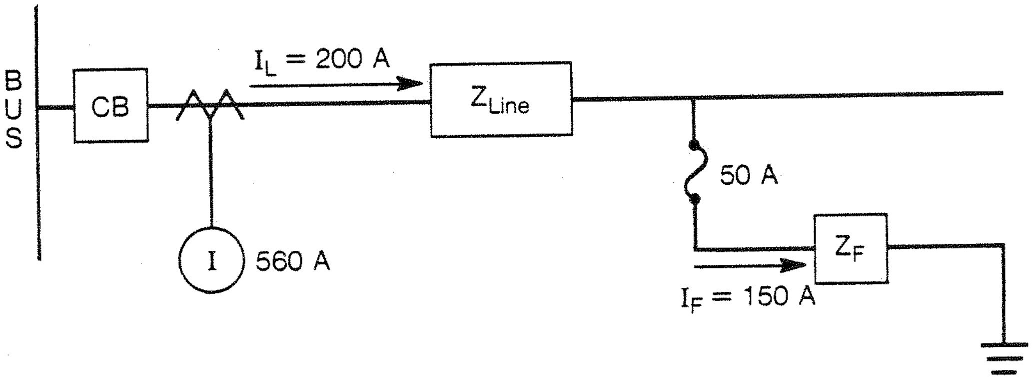

Figure 2. Not a "high impedance" fault. The fuse will clear the 150A fault.

In visualizing high impedance faults, we frequently think of a broken wire that contacts earth in some way--like falling into a tree or upon the earth surface. There are a number of possible conditions. If the conductor is broken,

- source and load ends can both be grounded.
- source end can be grounded, load end can be clear.
- source end can be clear, load end can be grounded.
- source and load ends can both be clear.

If the conductor is intact,

- it can contact a tree or other grounded object.

Undetectable faults of these types can reduce service reliability, promote customer complaint and constitute safety hazards.

The Electric Power Research Institute (EPRI) project to research the high-impedance fault detection problem did not break virgin ground. The IEEE Power System Relay Committee has been active in identifying and documenting the problem (1). Pennsylvania Power and Light Company, aside from being a contributor to Reference 1, is presently testing a solution they developed with Westinghouse Electric Company (2). Rochester Gas and Electric Company has been deeply involved in a search for a solution and participated in the EPRI project by staging fault tests for each of our three contractors. Warrington, in his book on protective relaying (3), discusses the problem, and Carr conducted a study for the Canadian Electric Association (4). New work on this subject is constantly surfacing, as by Graham, et al. (5). Many utilities are engaged in varying degrees in seeking solutions to the problem of identifying high-impedance faults.

In 1977, EPRI received eight responses to a Request for Proposals to research high-impedance fault detection. The importance of the subject, as well as the expected difficulty in arriving at a suitable solution, led us to accept three proposals, and contracts were subsequently negotiated with Power Technologies Incorporated (PTI), Hughes Research Laboratories and Texas A&M University (TA&M). Each contractor was to pursue an independent line of research, Texas A&M and Hughes being directed toward hardware development and PTI toward an analytical solution.

PROJECT RESULTS

Power Technologies Project - RP1285-1

In RP1285-1, PTI examined the changes that take place in the voltages and currents when a high impedance fault starts. The changes can be very subtle and embedded in the "noise" of the dynamic, constantly varying characteristics of the normal distribution system. It was concluded that no single characteristic could be relied upon to identify the onset of a fault. Noting that the characteristics most likely to exceed the noise threshold were the fundamental, and third and fifth harmonic components, analysis of these currents confirmed that they were potential identifiers.

Further analysis of the sequence components of these currents led to the conclusion that changes in the magnitude and phase of sequence currents could be expected with the onset of a high impedance fault. Under balanced conditions, the fundamental is a positive sequence current; the third harmonic, zero sequence and the fifth harmonic, negative sequence. A condition causing an unbalance, a fault for example, (three phase high impedance faults are rare) can therefore be expected to cause the two remaining sequence currents to flow at each frequency.

Table 1 shows the six sequence currents of interest. Since each of these is composed of real and imaginary quantities, a total of twelve quantities will change upon the onset of an unbalanced condition.

Table 1

Frequency	Sequence Current of Interest		
	Positive	Negative	Zero
Fundamental		X	X
3rd Harmonic	X	X	
5th Harmonic	X		X

In real life, however, a distribution feeder is never in perfect balance, and furthermore, the unbalance varies constantly. The twelve quantities represented in Table 1 are therefore always present to some extent, varying constantly in magnitude. To implement a fault detection scheme using these varying quantities, it is necessary to keep track of them on a real time basis, and to interpret changes as either a fault or no fault.

A statistical method was developed for doing this, and it was evaluated using normal system data taken at United Illuminating Company and fault data taken at Rochester Gas and Electric Company. Typical results of the evaluation are shown in Table 2.

Table 2

Feeder	Miss Probability	Minimum % Load Loss to Indicate Fault		
		0-4 hr	4-8 hr	8-12 hr
1	Pmiss = .5	5.6	6.1	7.3
	Pmiss - .1	8.9	8.4	9.0
2.	Pmiss = .5	7.5	10.2	8.3
	Pmiss = .1	10.4	13.2	11.3
3.	Pmiss = .5	5.6	5.6	4.7
	Pmiss = .1	6.8	8.2	5.7

For this single phase fault case, the time delay was set to two minutes and the false trip probability set to zero. It is seen that over the 12 hour period analyzed, faults involving a load loss of between 4.7% and 10.2% would be detected 50% of the time. Faults resulting in load loss of between 5.7% and 13.3% would have a 90% probability of detection.

Although this scheme has been extensively evaluated by such methods, additional evaluation in real time is needed. Implementation using a microprocessor is staightforward, and it would be most convenient to add this function to a computer controling other distribution automation functions. We are presently investigating the possibility of implementing this scheme in RP1472, "Integrated Control and Protection of Distribution Substations and Systems." We can, at very little cost, evaluate the scheme on an operating system, and examine the functional trade-offs that are possible with a flexible, microprocessor based system.

Hughes Research Laboratories Project - RP1285-2

Having performed some experiments using third harmonics before submitting their proposal, Hughes proposed to develop high-impedance fault detection techniques based on third harmonic current changes. We recognized that little was known of third harmonic behavior on power systems, other than that it is generally there to some extent or other; however, we felt that the use of third harmonic properties offered a reasonable potential for finding a successful detection technique.

Early in this project, Hughes observed that third harmonic currents existed in two basic forms--relatively high and steady magnitude, and low, rather variable magnitude. The high magnitudes, 2 to 4% of 60-Hz current, well above system noise levels, were associated with source feeders that had a predominance of grounded wye connected transformers and secondary load. The low magnitudes, 0.1 to 0.2% of 60-Hz current, embedded in system noise, were associated with feeders that had a predominance of delta-connected transformers or secondary load.

The onset of a high-impedance fault triggered a permanent phase shift of high-magnitude third harmonic current, and a very large increase in the amplitude of low-magnitude third harmonic current. Since these phenomena occurred consistently, two detectors were designed, one for application on each kind of system.

After capability verification by recorded fault and system data, two phase shift and three amplitude detectors were installed in monitor service on three utility systems. A tendency of the phase detector to false trip was reduced by a design modification without reducing the sensitivity of the detector to respond properly to the recorded faults. One phase detector still remains in service at this time.

The capabilities and limitations of the detector are summarized as follows:

o Single line-to-ground arcing faults having 15 amperes or more of current can be detected with a high degree of confidence. Since most faults of 15 or more amperes arc, the undetectables are those involving covered wire or highly nonconductive earth surfaces. However, the detection algorithm is such that only single line-to-ground faults can be detected. Initially, this was not considered to be a serious limitation because survey results indicated that single-phase faults predominated. However, the only high-impedance fault encountered by a detector in field service happened to be a double line-to-ground fault that was closed in on by the feeder breaker.

- High-impedance faults closed in upon by the feeder breaker are undetectable.

- The detectors properly ignore load and capacitor switching events

However, while we know more about third harmonic behavior now than at the start of the project, there are things we still do not know. This is evidenced by the unexpected and unexplained phenomena that caused the false trips. The design modification has reduced the false trip probability, but there is a degree of uncertainty as to its universal effectiveness.

Input requirements for the detectors are the currents in the relay CT secondaries. The line current as well as the filtered third harmonic are used in the detection as shown in the phase shift detector block diagram, Figure 3, and the amplitude detector diagram, Figure 4. Decision thresholds used in the detectors are based on observations made from staged fault and system normal data recorded on several utility systems. At this point, there are no specific application rules. The user would have to observe the third harmonic on the specific feeder to select the proper detector and to assist in setting the threshold values.

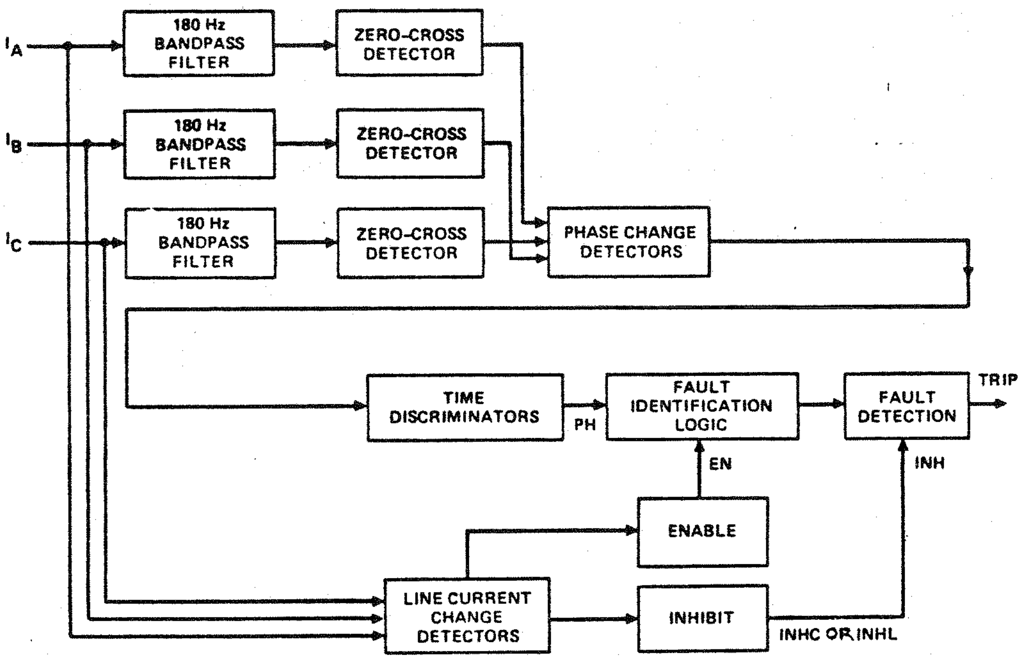

Figure 3. Hughes Phase Shift Detector Block Diagram

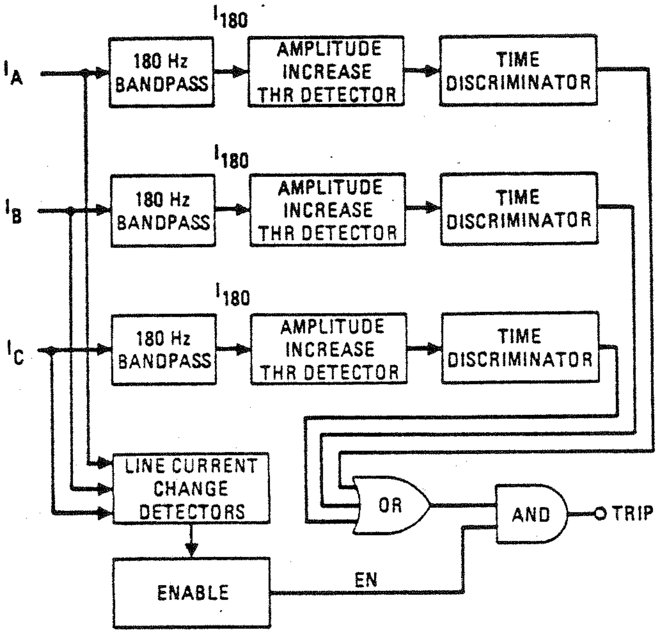

Figure 4. Hughes Amplitude Detector Block Diagram

Texas A&M Project - RP1285-3

The approach taken by Texas A&M was to build upon work they had performed that used the high-frequency noise generated by the arcing in a high-impedance fault as a characterizing agent.

A microprocessor-based detector was built and tested using feeder current recorded during staged faults and other routine system events. The prototype was subsequently installed in a substation where it was subjected to further staged fault and routine switching tests. It remained in service in a monitor mode for several months.

The capabilities and limitations of the detector, determined during the laboratory tests and field demonstration, can be summarized as follows:

- High-impedance arcing faults that draw 10 or more 60-Hz amperes can be detected with a high degree of confidence. Faults involving covered wire or highly nonconductive earth surfaces, such as macadam, usually have less than 10 amperes of current and/or do not arc, and therefore are not usually detectable.

- High-impedance faults that are closed in upon by the feeder breaker can be identified, usually within about 20 seconds after breaker closure.

- The detector properly ignored other events that commonly occur on distribution feeders, such as high-current faults, load switching and capacitor switching and any other unidentified events that might have occurred during the period of its installation.

- Grounded wye connected capacitors on the feeder shunt a large portion of the signal required for high-impedance fault detection to ground. Although this action was anticipated, there was some hope that sufficient signal would arrive at the substation to be recognized. Tests eventually showed that the detector did in some cases recognize a fault in the presence of capacitors, but in general, detection was erratic and unreliable. The cure, installing high-frequency traps on the capacitors, has not been

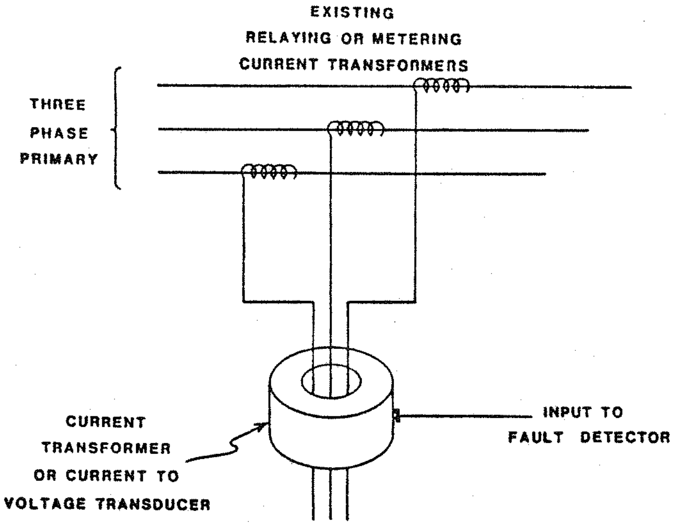

Figure 5. Detector Input Schematic

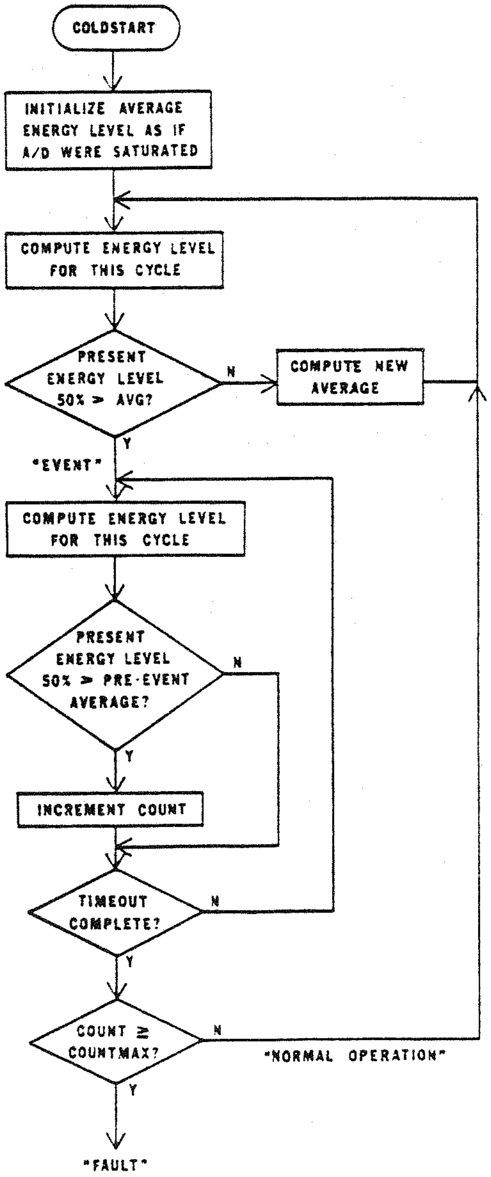

Figure 6. Flow Chart of
Texas A&M Detector

tried, but the expense of using traps would probably restrict the use of the detector unless the traps were required for some other purpose.

- The high-impedance fault signal generated on a feeder may couple into other feeders connected to the same bus, causing the detectors on those feeders to false trip. It is believed that a more sophisticated detector algorithm would overcome this drawback.

Input intelligence for the detector is derived from the summation of the three phase current transformer secondaries. To provide a satisfactorily high input voltage to the detector, a current-to-voltage transformer is used rather than simple shunts in the secondary leads, as shown in Figure 5.

The analog input signal is filtered to eliminate frequencies below 2 kHz, then amplified and converted to digital form for processing by the microcomputer. The flow chart of the detection algorithm is shown in Figure 6. It should be noted that the thresholds for decision making were set from observation of feeder current recordings so as to maximize detection capability and minimize false trip probability. For application to a specific feeder, it would be wise to make some preliminary current recordings to allow the best judgement of threshold settings to be made.

SUMMARY

The problem of timely and positive detection of high-impedance faults is not yet solved, but we are farther down the road than we were. We have three potential solutions, each with definite capabilities as well as definite limitations. Without additional field experience it is difficult to quantify confidence limits, especially in view of the limitations.

The Texas A&M detector would be almost useless for the companies that use grounded wye capacitor banks. With capacitor traps, the detector would probably be very useful, but the cost of trap installation would probably make widespread use of the detector economically unattractive.

The Hughes detectors have an unknown, but positive degree of success potential right now. Additional modification can improve the success potential, but the overall lack of understanding of third harmonic behavior would probably result in a general reluctance to use the detectors until additional performance statistics become available.

The hardware cost to implement the PTI analytical system of detection is a drawback that will be hard to overcome until computers in substations become commonplace. Even then, the system would have to receive extensive trial to determine its performance record.

The end point of each of the three projects was essentially determined by the exhaustion of the funds we had allocated. Our expected goals were not fully accomplished, but in each project we had reached a point where we could step back and view each in the perspective of the others. We can see that a field implementation of the PTI analytical approach has a potential for improving our understanding of third harmonic behavior, and thus may lead to improvement of the Hughes detectors.

We would like also to quantify the performance of the TA&M detector with capacitor traps. I would not rule out the possibility of combining one or more techniques in the same instrument, or in a "smart" relay package. I believe that the quantity price of either a Hughes or TA&M detector would not cost more than a conventional overcurrent relay package. Once you have the microprocessor system that both of these are based on, combination of functions is relatively simple and economical.

Reports on each of these projects are now in final draft form and should be available by the end of this year, or early in next year. Tables 1 and 2, and Figures 3, 4, 5 and 6 were taken from these reports.

ACKNOWLEDGEMENTS

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REFERENCES

1. IEEE Power System Relaying Committee Report. The Interruption of Downed Conductors on Low Voltage Distribution Systems, October 1976.
2. Lee and Kilar. Improved Relay Scheme for the Detection of Fallen Conductors on Three Phase, Four Wire Distribution Circuits. Presented at IEEE-PES 1979 T&D Conference.
3. A. R. van C. Warrington. Protective Relays, Their Theory and Practice, Vol. 2, London: Chapman and Hall, 1969.
4. Carr Engineering Ltd. High Impedance Fault Detection on Primary Distribution Systems. Report 78-75 prepared for the Canadian Electrical Association.
5. Graham, Carlson and Granberg. Broken Conductor and High Impedance Fault Detection by High Frequency Impedance Monitoring. IEEE paper A80064-6 presented at the 1980 PES meeting, New York City.