Detection and Location of Faults In Power Transmission Lines To Protection And Maintenance of A Power System

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ABSTRACT:

The detection and location of faults on power transmission lines is essential to the protection and maintenance of a power system. Most methods of fault detection and location rely on measurements of electrical quantities provided by current and voltage transformers. These transformers can be expensive and require physical contact with the monitored high voltage equipment. In this work, current transformers were replaced by magnetic field sensing coils. Such coils can be located remotely from substations and switching stations and do not require physical contact with the conductors. Rather than observing each individual conductor, the use of the magnetic field sensors allows the monitoring of the transmission line condition using a collective quantity. This study explores the use of the magnetic field sensors as an alternative measurement device for fault detection and location.

Keywords: Faults Lines, Magnetic Field Sensors, Power Transmission Lines, Power System.

INTRODUCTION:

FAULT detection/location on transmission lines is a very well-known problem that has been studied for a long time. An accurate fault detection/location technique is of special importance in improving power system reliability including relaying, analysis for line inspection, and routine maintenance. In the past, the most common approach was to model transmission lines using phasors. This approach is referred to as impedance based measurement technique, and is classified to two methods. The earlier developed one is one-terminal data method, and the other is the currently more prevalent one so-called two-terminal method. These methods use voltage andcurrent phasors to determine the impedance to the fault location, and both suffers from errors mentioned in many papers. For example, the one-terminal data method needs to make some assumptions for ground condition; the two-terminal impedance based method usually needs accurate and synchronized measurements for extracting the phasors.

A variety of methods of detecting and locating faults on power transmission lines exist. Most of these methods utilize the measurements from voltage and current transformers at substations or switching stations to perform their analyses. This thesis examines the effectiveness of using magnetic field sensing coils as alternative measurement devices for the purpose of fault detection and location. A review of common methods of fault location is presented. This review is focused on impedance-based and traveling wave-based fault location as they are the most common traditional methods. A few previous uses of magnetic field sensing coils in fault detection and location schemes are also discussed in order to determine the previously recognized benefits of using such coils.

The underlying mathematics used in determining the magnetic field due to an unspecified number of conductors and due to a three-conductor system are then examined. The results of this analysis are used in simulating the magnetic field for a variety of conductor configurations under normal operating conditions and for line to ground and line to line fault conditions. This information is used to determine the potential effectiveness of monitoring the magnetic field to detect faults. Based on these findings, four algorithms are constructed which monitor the magnetic field near the transmission line for the purpose of fault detection. Each of these algorithms determines some aspect of the steady-state behavior of the magnetic field and attempts to detect any deviations from this behavior. These algorithms are described in detail and their comparative benefits and drawbacks are determined. These problems are completely solved by the proposed adaptive technique presented in the paper. The algorithms of an adaptive transmission line fault detection/location technique are presented.

The adaptive fault detection/location technique uses synchronized fundamental voltage and current phasors at both ends of transmission line, and of course, requires an extremely accurate common timing reference. In the past, it was difficult to precisely synchronize the sampling at the ends of transmission lines due to the lack of a common timing reference. At an early stage, it usually adopts broadcast signal as timing reference, or utilizes telecommunication technique to transmit remote data to the control center. However, these introduce new problems i.e. there will exist multi-path effects or it needs to precisely determine the delay of communication channel and to correctly compensate for this delay. Now, using the accurate timing signal provided by Global Positioning System (GPS) as common time base for measuring instruments located at both ends of line, we can highly promote the accuracy of synchronized measurements and reduce the cost of equipment greatly. Because of low frequency of the timing signal of GPS, it cannot be used as sampling signal directly. This means that a timing device is needed to do frequency multiplication/division task. The study presents the hardware and software design of such a timing device and investigate performance of this device through field-test in the paper.

An implementation of a complete fault detection and location procedure which uses these algorithms in conjunction with one another is then described. This implementation is then used to test the combined effectiveness of the algorithms for a variety of fault types and fault resistances. The fault location errors for these tests are then presented. This information is used in determining the effectiveness of the magnetic field sensor as a measurement device for the purpose of fault detection and location. The proposed PMU based fault detection/location technique incorporated with line parameter estimation forms an adaptive technique. The adaptive fault detection/location technique can cope with various factors associated with the accuracy of fault detector/locator mentioned above. Its performance will be evaluated with respect to various factors such as fault resistance, source impedance variation, line loading, fault incidence angle, etc.

Impedance-Based Methods

Traditional impedance-based fault location methods use the voltages and currents at one or both ends of a transmission line to determine where a fault has occurred. The impedance of the transmission line per unit length is usually required in these calculations. One of the major problems with basic one-terminal impedance-based fault location methods – those that only use measurements from one end of the transmission line – is that the fault impedance must be near-zero for the result to be accurate, since the fault impedance affects the impedance seen at the end of the transmission line. This problem has been mitigated in several different ways. One of the best-known of these ways is the Takagi method. This changes the calculation to include the difference between the current measured before the fault and the current measured after the fault (which is the fault current). This eliminates the fault impedance from the analysis, thus removing this significant source of error. However, the angle of the fault current and the angle of the current during the fault at the relay terminals are assumed to be equal; if this is not true, there may be errors in the fault location. Two-terminal impedance-based fault location methods, or those that use measurements from both ends of the transmission line, can also significantly improve the accuracy of the fault location estimate [1]. Two-terminal methods require communication between the locators at both ends of the transmission line to transfer information about the currents, voltages, and source impedances in order to perform the fault location. Once all of the necessary information is gathered in one location, the fault is located by combining the equations describing both sides of the transmission line and variables directly related to the fault; the exact analysis depends on the particular algorithm.

The use of both sides of the transmission line in calculation removes most of the problems associated with one-terminal impedance-based fault location methods. It is essential to note, however, that short-duration faults are difficult to accurately detect with any impedance-based fault location methods (although two-terminal methods reduce the effect of short fault durations) since less data is available about the voltages and currents and the data that is available is not necessarily in steady-state.

IMPLEMENTATION OF PHASOR MEASUREMENT UNIT

PMU Configuration

As mentioned in Part I, the phasor approach is quite attractive as long as all of the algorithm assumptions are met and phasor quantities are estimated accurately. It is widely recognized that two-terminal based fault detectors/locators are subject to errors coming from unsynchronized sampling clock. Use of a timing signal from GPS can greatly reduce or eliminate such errors. In this paper, we proposed an extremely accurate configuration for measuring phasors by virtue of Phasor Measurement Units (PMU) technique, whose configuration. The GPS receiver provides 7 pps (one pulse-per-second) signal and a time marker, which are sent to GSCG and microprocessor respectively. The 1 pps signal will be utilized to process the frequency multiplication/division task in the GSCG, and then GSCG provides synchronized sampling pulses to the A/D converter. The measured 3 voltages and currents are digitized by A/D converter, and then fetched into microprocessor. The microprocessor determines the phasor according to built-in recursive SDFT program, and the time marker information from GPS is assigned to the phasors as their identifying tag. These time-marked quantities are transmitted to remote site through the communication channel.

GSCG Configuration

In order to reduce settling time, frequency jitter, and steady state errors, we design a new timing device named "Global Synchronism Clock Generator (GSCG)" whose timing error could remain within that of satellite's receiver. The block diagram and actual implementation of GSCG respectively. The vital core of GSCG is a microprocessor based phase locked loop (PLL). The PLL consists of time-error counter, microprocessor, digital-adjustable oscillator, and frequency divider. The time-error counter compares the difference between 1 Hz signals generated by GPS and frequency divider (divided by). Then, the error quantity is sent to microprocessor, and is processed with the time marked data provided by GPS receiver herein. Microprocessor uses a P–I type (proportional and integral) control program to correct the error quantity in sampling clock. Concurrently, microprocessor will transmit the clock signal to another frequency divider and from there the accurately synchronized clock output goes to two A/D converters.

The digital-adjustable oscillator is controlled by voltage provided by the microprocessor. Its output frequency is a function of the control voltage. The important merits of PLL utilized in GSCG are that it adopts close-loop feedback control scheme, and uses a gain-programmable oscillator. Hence, the new designed GSCG is a completely digitized timing device, its speed is very fast and is quiet suitable for the applications of computer relaying. Besides, the very lowcost for constructing the GSCG is another one of several merits of our design, for example, the crystal oscillator utilized in our GSCG costs merely 32 NT$ (about 1 US$). Moreover, another important advantage of GSCG is its ability to automatically compensate unsynchronization error by software built in microprocessor. From our investigations, the frequency drift of GSCG can be controlled within 0.1 PPM and the error of rising edge of two GSCGs clock is able to remain within 1 s (equivalent to 0.0126 phase difference at 60 Hz). These facts certify the synchronism between two PMUs when they are used to measure phasors at different ends of transmission line.

Performance Evaluation for Adaptive Fault Detection/Location Index

1) The Performance of Fault Detection: It is observed that absolute values of M and N will all be held at zero before the occurrence of a fault. This can be proved by substituting the measured data (V_s, I_s) and ($V_{R,}$ I_R) into the formulae of M and N, respectively. Since such measured components all satisfy the transmission line equation, after algebraic manipulation, we can prove that and are indeed identical to zero, and hence the algorithm will give an indefinite value of fault location index through. However, as soon as the post-fault measured data is input into the algorithm through the moving data window, the computed absolute values of M and N abruptly deviate from zero, and hence the fault location index also quickly converges to some value. After approximately the first two or three cycles of fault, the computed absolute values of and would stabilize, and they would gradually stabilize to a constant gap between each other. While the computed absolute values for M and N will take two or three cycles to converge to stable values, the fault location index D (for most of fault-types) takes much less time to achieve a stable value. These facts imply that M and N location index D could be employed as detection index of fault. Many fault events have been tested with respect to different fault-types, different fault resistance, and various fault locations in our simulation. The typical fault detection response for single-phase-to-earth fault involving a 1- fault resistance to ground in -phase. The fault time and fault location are set at 37.47 milliseconds and 80 kilometers away from the receiving end, respectively. When the measured post-fault data were fetched in the algorithm, the computed and values quickly deviated from zero, finally reaching stable values. The location index abruptly converged to 0.8. As mentioned above, the fault detection performance of the proposed algorithm is well suited for any type of fault events. This case is a – phase ground fault case, whose fault resistance and fault location are set at 10 k and 80 km, respectively. While this case is a high fault resistance case, clearly

shows that the proposed index once again provides excellent performance for fault detection. The fault detector is regarded as failures to trip when it takes over the specified decision-limited periods. There are three specified decision-limited periods, i.e. 1-cycle, 1.2-cycle, and 1.5 cycle, are chosen as restraint periods for the simulation tests. In these tests, it is clearly seen that larger threshold of index is chosen, the more reliability of the fault detector possesses. When the threshold of is set at 0.0285, for example, the reliability of the fault detector can achieve even high to 100.0% and 98.41% with respect to 1.5-cycle and 1-cycle decision-limited periods, respectively. From the shown table, it is observed that the relaying scheme can indeed achieve an extremely high level of reliability.

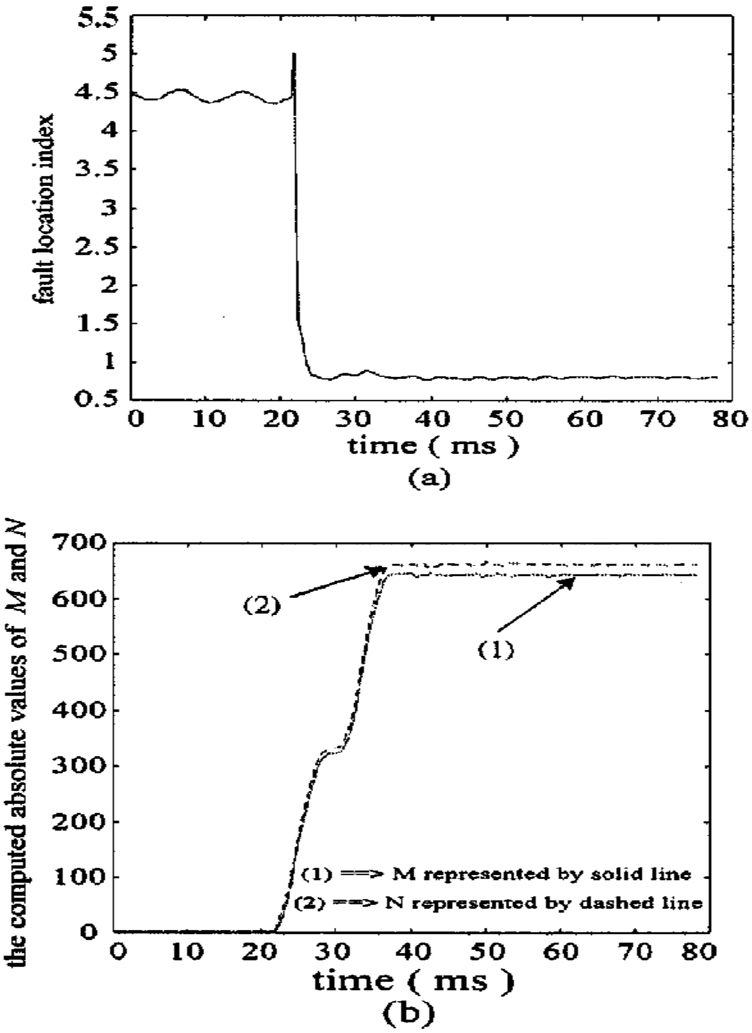

Figure 0: Detecting the occurrence of b–c phase ground fault whose fault index and fault resistance are D = 0:8 and R = 10 k, respectively.

Testing the Algorithm

The full algorithm was tested to determine the accuracy with which it can detect faults. The system was tested for a 115kV transmission system. The geometry of the transmission line and details about its simulation model are presented. Single line to ground faults were used as the main fault for testing since they are by far the most common fault types; the conductor configuration was chosen as a coplanar arrangement. Since the accuracy of calculation is dependent upon the angle of fault incidence, the system was tested for faults at both the zero crossing of the faulted phase's current, which is the most difficult fault timing to detect, and at the faulted phase's peak current, which is easiest to detect. The testing was based upon a purely resistive fault. The location of the fault was varied linearly along a 20km transmission line for fault resistances of 0.1, 1, and 10 per unit, which are equivalent to approximately 13.225Ω, 132.25Ω, and 1322.5Ω for the 115kV transmission line in question.

$$Z_{base} = \frac{\left(kV_{LL,base}\right)^2}{MVA_{3\phi,base}}$$

These values come from for the given base voltage of 115kV line to line and a chosen base 3-phase power of 100MVA which results in a per unit impedance of 132.25Ω. The sampling rate used in this testing was 2MHz. For all tests, any frequencies below 60Hz and any harmonics are assumed to have been filtered in a way that does not noticeably affect the fault detection. Additionally, the magnetic sensors are assumed to be able to respond to a change in the magnetic field instantaneously. Also, noise is assumed to be negligible.

The fault simulations were conducted using ATPDraw, a free electric power system analysis program; the resulting data was exported into Microsoft Excel using TOP, an output processor for power system analysis programs. The Excel-format data was then processed by MATLAB using the code in Appendix C. In an actual power system setting, only the actual analysis step (here represented by the MATLAB analysis) would be performed, thus simplifying the process significantly. The fault location error is specified.

$$Error\% = \frac{d_{read} - d_{actual}}{l} \times 100$$

It is equal to where dread is the fault location detected by the algorithm, dactual is the actual location of the fault, and l is the total length of the transmission line. If a fault was detected with only one of the algorithms, this detection was not discounted. It is clear from a comparison between the accuracies of the fault detections for zero-crossing current faults and the fault detections for peak current faults that the fault location is much more reliable for faults at the peak of the current. In fact, the curve in (which is the best-case situation for fault location) is independent of fault resistance until the fault resistance becomes larger than 10 per unit (1322.5Ω) which is the resistance for which this Figure is plotted. The faults at the current's zero-crossing were not detected at one end of the transmission line (thus preventing fault location) for fault resistances greater than 1 per unit, which is 132.25Ω. (Note that the algorithm did detect and locate the faults at 10% and 20% of the transmission line length at this impedance, but the accuracy was incredibly poor and thus the points do not appear). For the sake of comparison, ground fault resistances may be as high as 800Ω "[i]n cases of high ground resistivity and no overhead ground wire". While this is a relatively high impedance for a ground fault, it is still possible that a fault of this impedance could occur near the zero-crossing of the faulted phase's current and that as a result this algorithm would not be able to detect or locate the fault. This is one of the admitted weaknesses of this algorithm. As a result, this implementation of the fault detector can only be recommended for use with transmission lines that have at least one overhead ground wire.

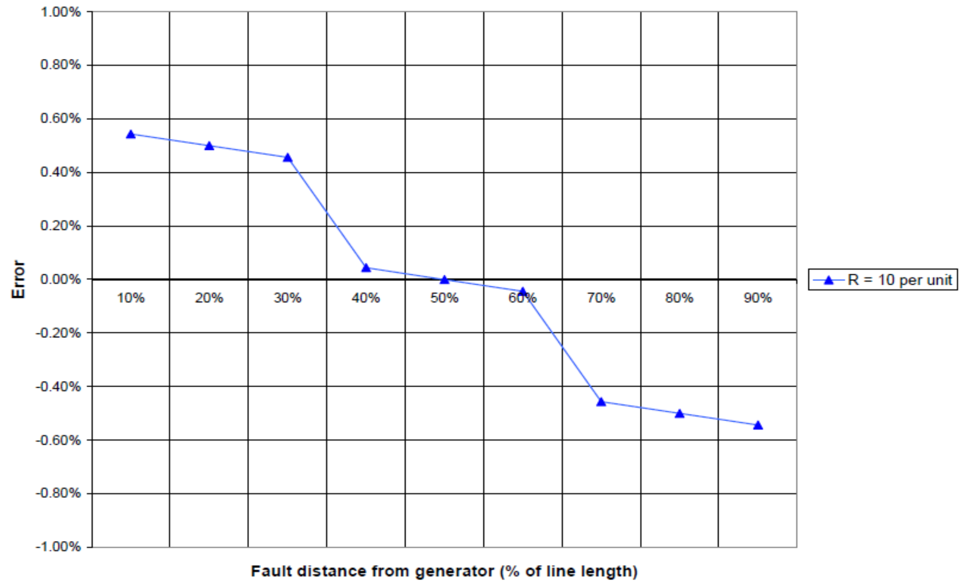

Figure 1: Fault location error for a single line to ground fault when the faulted phase's current is at a maximum

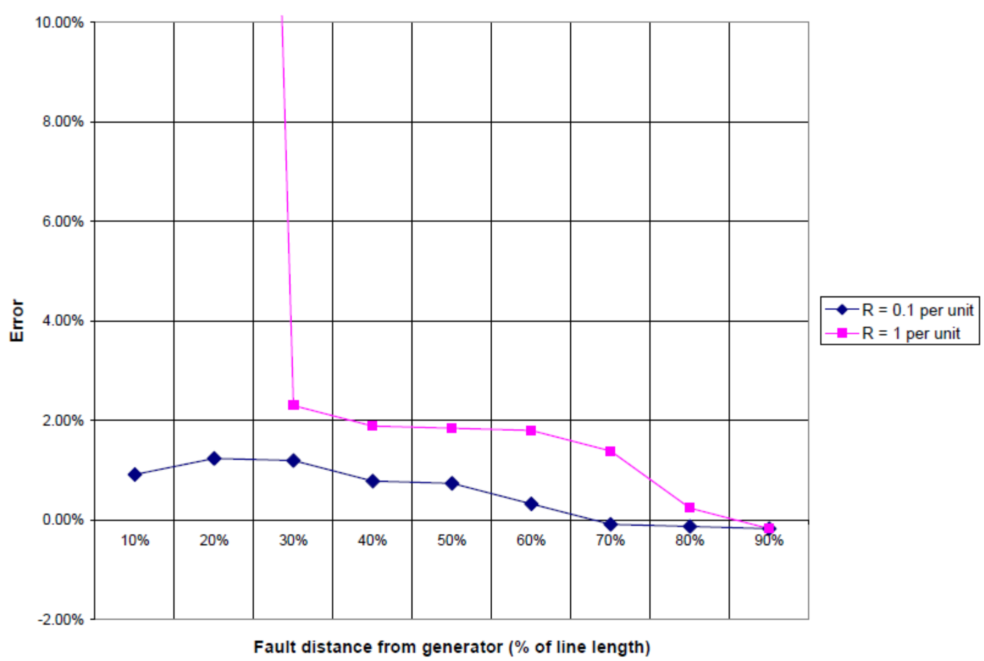

Figure 2: Fault location error for a single line to ground fault when the faulted phase's current is Zero

The algorithm was also tested for a range of fault resistances for each major fault type, including single line to ground faults (at both the faulted phase's current maximum and current zero-crossing), line to line faults and line to line to ground faults (when both phases' currents are at identical values), and three phase faults (at one of the phases' current zero-crossings). The timings above are the most difficult portions of the cycle to detect each of these faults, with the exception of the single line to ground fault at the faulted phase's current maximum which was included since it was already tested based on fault location. The faults tested were located in the center of the transmission line (10km from each end) in order to minimize the faults appearing to be undetected when the problem is simply a large error. For example, if a fault is very close to one of the ends of the transmission line and the other end does not detect the fault exactly when the traveling wave arrives, the fault will appear to be off of the transmission line and, based on the way the analysis algorithm is designed, will be seen as an erroneous fault detection.

The results extremely accurate fault detection. Aside from the slightly low detectable fault impedance for the worst case of single line to ground faults as previously mentioned, the only fault type where moderate fault impedances seem to cause a problem is the line to line fault. As can be seen in Appendix B, this fault location must rely specifically on detecting sudden changes in theta to produce an accurate result. By decreasing the allowable range of values of delta theta, the maximum detectable fault impedance could be increased; however, this would make the algorithm more likely to incorrectly detect faults due to noise.

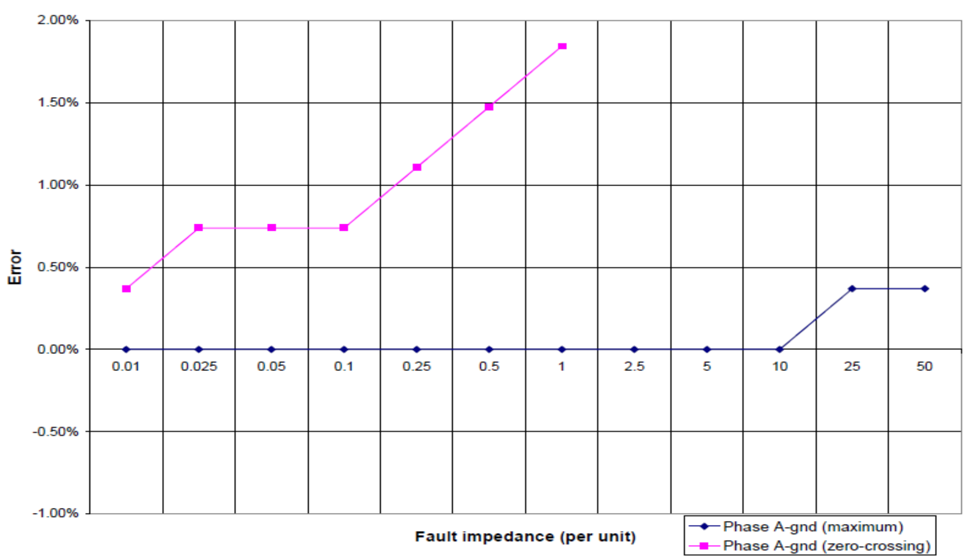

Figure 3: Fault location error as a function of fault impedance for single line to ground faults

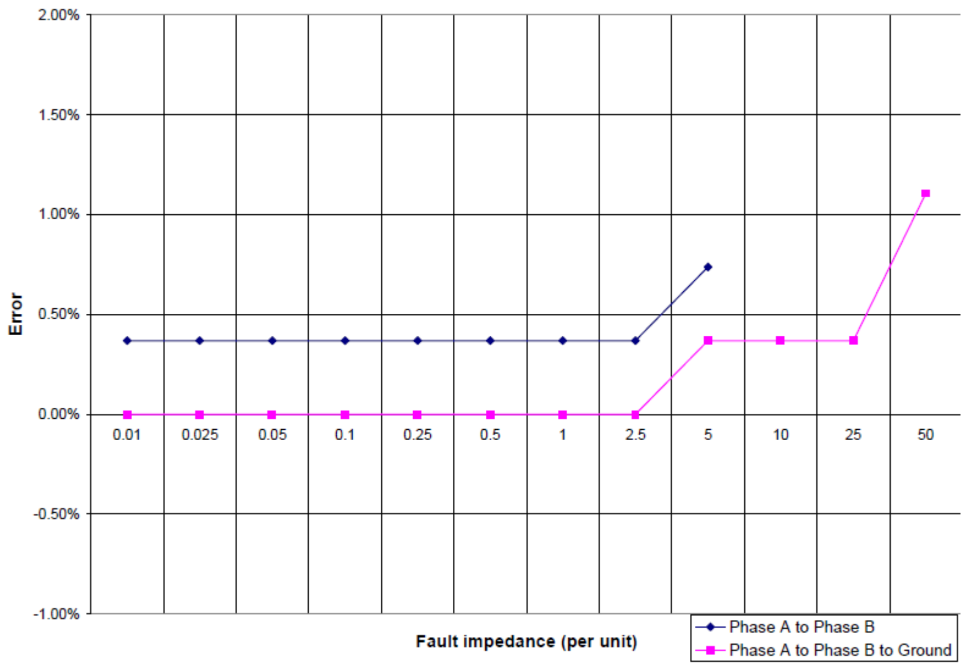

Figure 4: Fault location error as a function of fault impedance for line to line faults

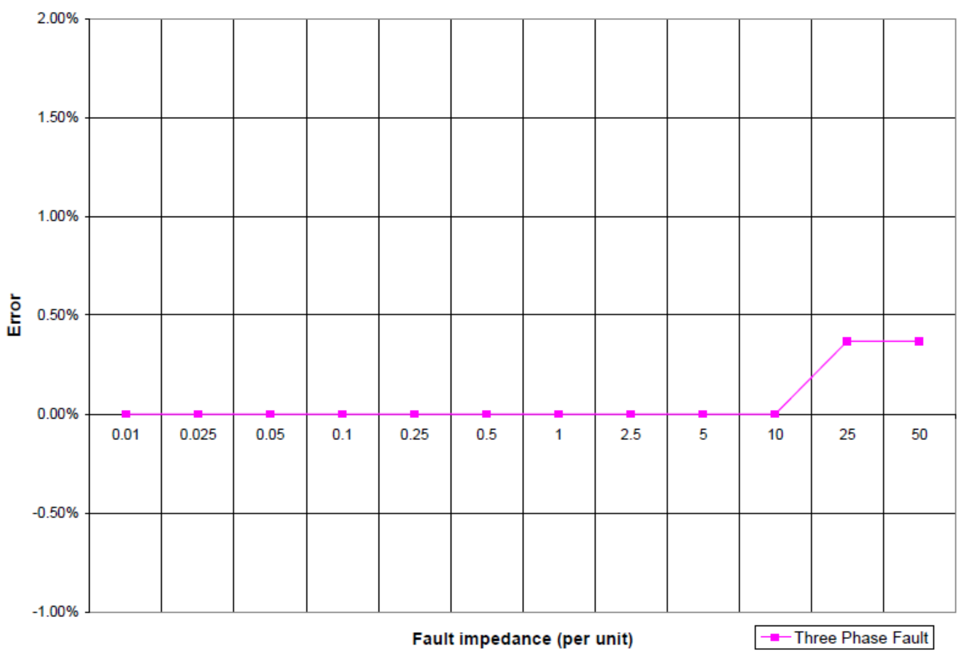

Figure 5: Fault location error as a function of fault impedance for three phase faults

The slightly jagged nature of these Figures is due to the fact that the error is limited to a discrete set of values for a given fault location since the calculated fault locations are also limited to a discrete set of values. This due to the step size discussed and is a result of the sampling rate. Higher sampling rates than the 2MHz which was used in these tests can decrease this appearance and may also improve the accuracy of detection, depending on the location of the fault in question. The errors shown are on the order of hundreds of meters since 1% error is equal to 200m for the 20km long transmission line. This is in the range of the maximum error introduced by the synchronization using GPS. As a result, significant improvements in the accuracy of these algorithms will not necessarily provide a worthwhile benefit at this time.

It is also important to note that the fault detection error and maximum detectable fault impedance are based on the margins of allowable operation for each algorithm. For example, the code in Appendix C which was used to carry out these tests requires the change in rho at any time to be greater than double the maximum detected change in rho for a fault to be detected. Reducing this allowable margin will increase the location accuracy for correct fault detections and will make higher impedances easier to locate but will also make it easier for the algorithm to detect faults incorrectly.

CONCLUSIONS

This thesis described the theory and methods of traveling wave fault detection and location using magnetic field sensing coils. The concept of the magnetic field for a general and three phase system was explored. This was followed by a presentation of the magnetic fields for a variety of conductor configurations and sensor locations. The four algorithms used in the magnetic field-based fault detection were then described. Finally, the combined algorithm was explained, and the results of accuracy and maximum detectable fault resistance were presented. The magnetic field sensors were shown to be effective in detecting faults conceptually. Additionally, the collective algorithm was tested and was shown to provide accurate fault detection for relatively high fault impedances and for each common type of fault. All of this proves the magnetic field sensor to be a viable tool for power transmission line fault detection.

Future research could be performed in applying these algorithms to more complete systems than the single transmission line which was used for analysis in this thesis. Additionally, other fault location algorithms – most specifically, a fault location and classification scheme using the wavelet transform – could be modified to make use of the magnetic field. This will most likely improve the accuracy of fault location and increase the maximum detectable fault impedances.

Eventually a prototype of the magnetic field-based fault detector could be built and field tested. This would require more development of the sensor coils as well as harmonic-filtering circuitry. The MATLAB code would also need to be reconfigured since it is currently written to analyze pre-prepared sets of data to test the algorithm rather than to continuously monitor information with which it is provided. The programming language would also most likely need to be changed to a different language which could be compiled directly for use with a microprocessor.

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