SEMINAR REPORT

A NOVEL APPROACH FOR FAULT LOCATION OF OVERHEAD TRANSMISSION LINE WITH NONCONTACT MAGNETIC-FIELD MEASUREMENT

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ABSTRACT

Fault location and correction are important in case of any power systems. This process has to be prompt and accurate so that system reliability can be improved, outage time can be reduced and restoration of system from fault can be accelerated. The traditional systems adopted for fault location (travelling-wave-based approach and impedance-measurement-based approach) result in complexity, lack of economy, non-homogeneity and sometimes even cause unacceptable location errors.

The method for fault location explained here is one in which non-contact magnetic field measurement is utilized. In this, magnetic field is measured along transmission line using a highly sensitive, low-cost magneto resistive magnetic sensor, and fault span is located. The collected data can be utilized for identifying fault location within the fault span as well as the type of fault. The simulations carried out validate this scheme of fault locating.

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CHAPTER 1

INTRODUCTION

Fault location and correction are important in case of any power systems. This process has to be prompt and accurate so that system reliability can be improved, outage time can be reduced and restoration of system from fault can be accelerated. The traditional systems adopted for fault location are travelling-wave-based approach and impedance-measurement-based approach. The travelling-wave-based approach requires detection devices to connect to the high-voltage transmission line, making the solution complex and costly. And the impedance-measurement-based approach is highly dependent on the quality of the signal and affected by fault resistance, ground resistance and non-homogeneity in line configuration. Hence, these approaches may cause a location error that is unacceptable in certain operation cases.

The new method of locating of fault utilizes the new technology of magneto sensors which are used for finding the fault in transmission lines. It is a low-cost high-precision solution, which does not need to connect the device to the HV transmission line and is highly sensitive for fault location.

We all know that the fault is a condition causes abnormal flow of electric current. Faults are mainly two types

- Symmetrical fault

  e.g.; 3φ to ground fault
- Unsymmetrical fault

  e.g.; L-G fault, L-L fault, L-L-G fault

CHAPTER 2

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CURRENT METHODS

Several methods are currently used for fault locating. Some of them are

2.1 Impedance-based fault location

In the impedance-measurement-based technique, the voltage and current during prefault and post fault are acquired and analysed. The line parameters can then be calculated with the transmission-line model and the fault can be located.

Impedance-based methods require the following approach

- Measure the voltage and current phasors
- Extract the fundamental components
- Determine the phasors and fault type
- Apply impedance algorithm

One-ended impedance methods of fault location are a standard feature in most numerical relays. One-ended impedance methods use a simple algorithm, and communication channels and remote data are not required. One-ended impedance-based fault locators calculate the fault location from the apparent impedance seen by looking into the line from one end. To locate all fault types, the phase-to-ground voltages and currents in each phase must be measured.Impedance algorithm calculation is complex in nature. In certain cases error may reach 5% or even more. The installed system may cause an error of 3 km in 500-kV transmissionlines. The maintenance crew may have to walk 6 km in a rough terrain to determine the exact location of the fault point

Two-ended methods can be more accurate but require data from both terminals. Data must be captured from both ends before an algorithm can be applied.

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2.2 Travelling-wave-based fault location

Fault occurring on a power cable will generate both voltage and current traveling waves with wideband signals which cover the entire frequency range. These different frequency components will travel along the line until they meet a discontinuity on the line, such as the fault point or busbar. At this point, both a reflection and a refraction of the wave will occur. This generates additional waves which will propagate through the power system.

In the travelingwave technique, either the transient created by a fault is captured or impulses are injected into the line, and the reflected travelling wave is detected with time-domain reflectometery (TDR). The fault location is then determined by timing analysis of the travelling wave. As the faulted signal obtained at the end of the transmission line is highly mingled with noise, some modern signal processing techniques, such as the wavelet are used for fault location.In the traveling-wave based approach, the accuracy of the location is highly dependent on the performance of the costly high-speed data-acquisition system.

Furthermore, these methods fully depend on an assumption that the parameters of the transmission line are uniform. Considering the fact that the transmission lines are distributed over a large geographical area, this assumption is generally not entirely true. For example, the non-uniform spacing of the phase conductors may affect the inductance (although phase conductors are transposed to reduce the effect), temperature may affect the resistance, and sag may affect the capacitance in different transmission-line segments.

Operation experience shows that most of the systems can limit the fault-location error within1–2% of the monitored line length. In certain cases, the error may reach 5% or even more. The accuracy factor becomes even more important for long transmission lines because even a relatively small error would result in an uncertainty of a few kilometers, causing significant delay for the maintenance crew to find the fault location. Especially in areas over rough terrain (e.g., mountain area, forest area), the installed system may cause a large error. For nonpermanent faults, such as flashover caused by sag of stressed lines, considering their temporary nature, it may take even more effort to locate the fault point with these systems because the fault is not permanent and the system may have already resumed its normal condition by the time the maintenance crew arrives.

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CHAPTER 3

DRAWBACKS OF CURRENT METHODS

But both of these techniques have many problem associated with them. Some of them are

- The parameters of the lines are to be known
- Have to consider that the line is homogenous in nature, while in fact it is not
- The relative location error is very large many times
- Error occur when fault reactance is there
- Performance is highly dependent on signal processing techniques
- Have to connect instruments to the live line, which increases the cost of instruments needed
- Hard to map the electrical distance to actual geographical location
- Affected by CT saturation
- Have to assume uniform wave speed
- High speed data acquisition
- High cost

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CHAPTER 4

MAGNETORESISTANCE SENSOR

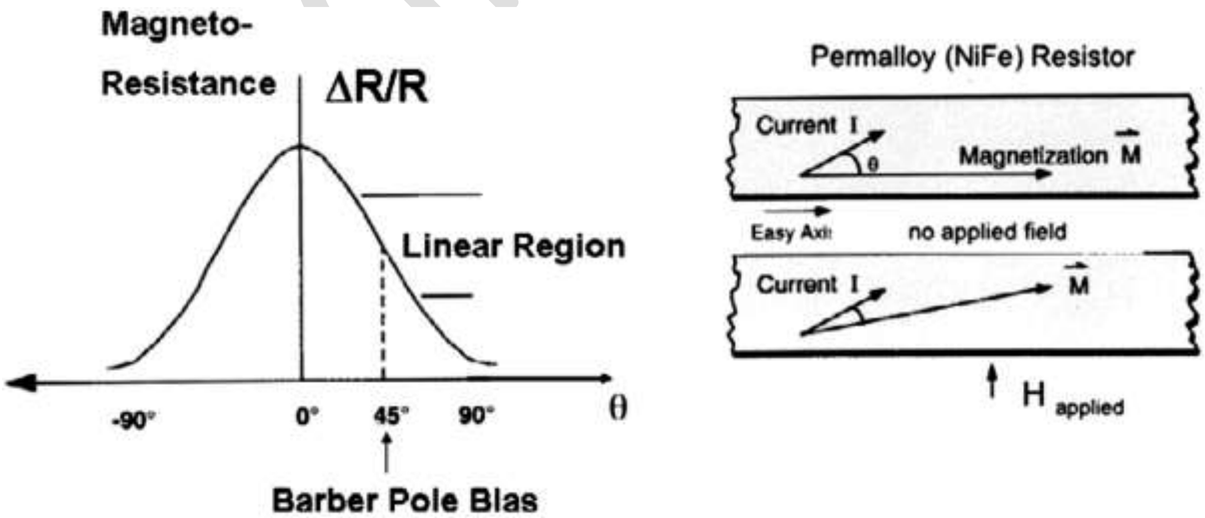
The MR magnetic sensor, based on the magnetoresistance effect is used in this application. Magnetoresistance is the property of a material to change the value of its electrical resistance when an external magnetic field is applied to it. The strength, direction, and distribution of the magnetic field emanated from the conductors contain information about the electric power parameters, such as amplitude, frequency, and phase of the electric current.

Recently, the anisotropic magnetoresistance (AMR), giant magnetoresistance (GMR), and tunneling magnetoresistance (TMR) materials are discovered and integrated into commercial magnetic-field sensors successfully. These sensors in general have high sensitivity, large temperature range, and wide frequency bandwidth (from dc to several megahertz). The recent advances in MR sensors make it possible to fabricate low-cost chip-scale magnetometers for detecting the 3-D vector magnetic field.

4.1 Anisotropic magneto resistance sensor

AMR sensors use materials, such as permalloy (an alloy containing about 80% nickel and 20% iron), whose resistance depends on the angle between the magnetization and the direction of current flow. The resistance changes roughly as the square of the cosine of the angle between the magnetization and the direction of current flow.

Permalloy is the most common material for AMR sensors because it has a relatively large magnetoresistance and because its characteristics are compatible with the fabrication techniques employed to make silicon integrated circuits. The magnetoresistance of permalloy is less than 4%.

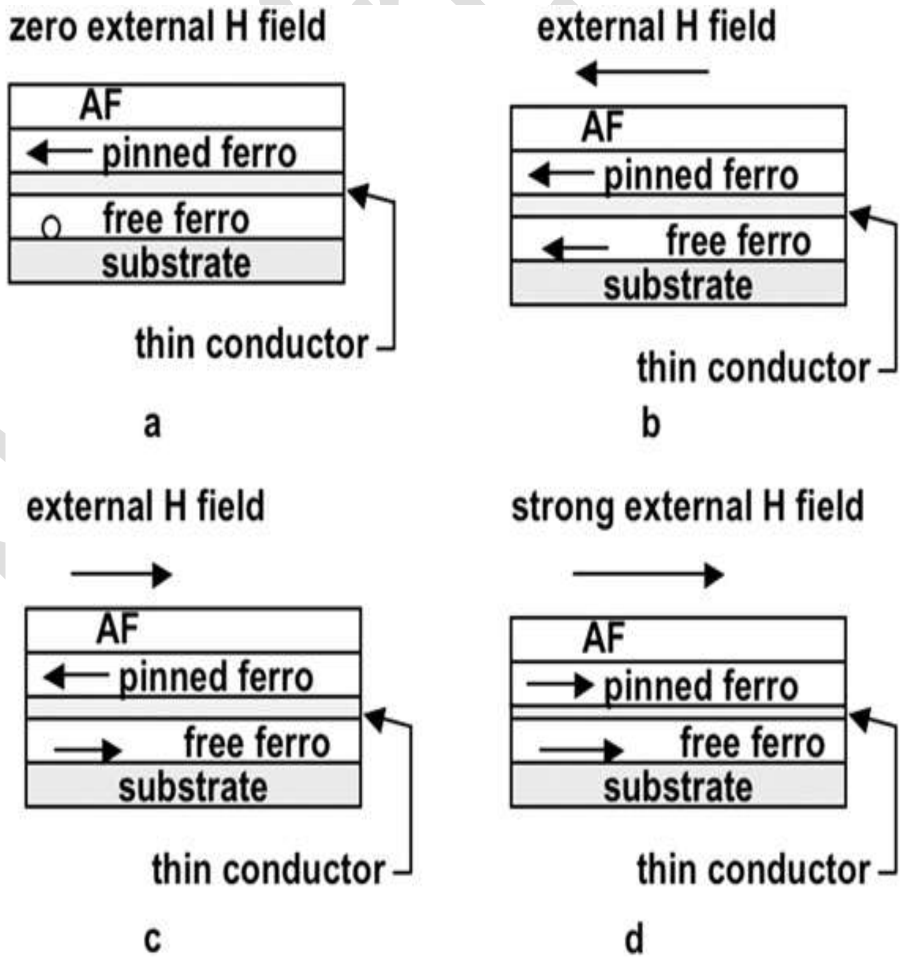


Anisotropic magnetoresistance (AMR) sensor: (a) resistance versus angle θ between the magnetization and the direction of current flow, (b) change in θ due to the application of a magnetic field.

4.2 Giant magneto resistance sensor

Larger changes in magnetoresistance were observed in planar structures of metals. The effect was named giant magnetoresistance or GMR. In its simplest form, called a spin valve, GMR is achieved by using a four layer structure that consists of two thin ferromagnets separated by a conductor. The fourth layer is an antiferromagnet that is used to pin (inhibit the rotation) the magnetization of one the ferromagnetic layers. The ferromagnet layer that is being pinned is between the conductor and the antiferromagnet. The pinned ferromagnet is called the hard ferromagnet and the unpinned ferromagnet is called the soft ferromagnet.

Electrons can travel more easily either parallel to the layers or perpendicular to the layers if the magnetizations of the two ferromagnets are parallel to one another. The reason for this is that when the magnetizations are parallel, electrons suffer less scattering in going from an electronic band structure state in one of the ferromagnets into a similar or identical electronic band structure state in the other ferromagnet. The difference in resistivity between the case when the magnetizations are parallel and when they are antiparallel can be as large as 12.8% at room temperature. To optimize the effect, the layers must be very thin, about a nanometre thick.



Orientation of the magnetization of the ferromagnetic layers in a GMR spin valve for different external fields *H*. (a) $H = 0$, the magnetization of the free ferromagnetic layer is perpendicular to the magnetization of pinned ferromagnet, $R = R(0)$. (b) Low resistant state, *H parallel* to the magnetization of the pinned ferromagnet, *R* <*R*(0). (c) High resistant state, *H* directed opposite to the magnetization of the pinned ferromagnet, *R* >*R*(0). (d) *H* large enough to unpin the pinned ferromagnet, *R* <*R*(0).

4.3 Tunneling magneto sensor

Magnetic tunnel junctions (MTJ) or spin dependent tunneling (SDT) sensors, first fabricated in 1995, have a structure similar to the four layer structure described above in GMR sensors. Again there are two ferromagnets separated by an intervening layer and the magnetoresistance is a function of orientation of the two ferromagnets, but in this case the intervening layer is an insulator. In MTJ sensors, the conduction occurs by tunneling of electrons through the insulator.

Based on a spin-polarized tunnelling model the magnetoresistance ratio *MR* or Δ*R/R* is given by

$$\frac{\Delta R}{R} = \frac{R_a - R_p}{R_p} = 2P_1P_2(1 - P_1P_2)$$

Where R_p and R_a are the resistances when the two ferromagnets are parallel and antiferromagnetic, respectively, and P_1 and P_2 are the spin polarizations of the two ferromagnets.

CHAPTER 5

PROPOSED METHOD

This method of locating of fault utilizes the new technology of magneto sensors which are used for finding the fault in transmission lines. It is a a low-cost high-precision solution, which does not need to connect the device to the HV transmission line and is highly sensitive for fault location

The sensors are placed on the tower, and the data are transmitted to a data-processing centre where analysis software can determine which span the fault location belongs to. The collected magnetic-field data can also be used to identify the fault type and even locate within the fault span.

This method utilizes fast advancement of the microelectromechanical systems (MEMS) packaging technology and magnetoresistance material technology. The MR magnetic sensor, based on the magnetoresistance effect is used in this application. Magnetoresistance is the property of a material to change the value of its electrical resistance when an external magnetic field is applied to it. The strength, direction, and distribution of the magnetic field emanated from the conductors contain information about the electric power parameters, such as amplitude, frequency, and phase of the electric current.

Recently, the anisotropic magnetoresistance (AMR), giant magnetoresistance (GMR), and tunneling magnetoresistance (TMR) materials are discovered and integrated into commercial magnetic-field sensors successfully. These sensors, in general, have high sensitivity, large temperature range, and wide frequency bandwidth (from dc to several

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megahertz). The recent advances in MR sensors make it possible to fabricate low-cost chip-scale magnetometers for detecting the 3-D vector magnetic field.

CHAPTER 6

STRUCTURE OF PROPOSED METHOD

The monitoring terminal is a small device integrated on a printed-circuit board (PCB) board. The entire system is composed of a microprocessor (CPU) and its peripheral devices [sensor module, data-acquisition (DAQ) module, storage module, communication module, signal preconditioning module, and power supply]. The microprocessor controls the entire system and performs DAQ of the magnetic signal continuously. The information in the signal can be extracted by simple analysis (e.g., amplitude calculation).

Once a certain change in the signal is detected, the data are stored and sent to the centre station through the communication channel. Since the system aims at serving a mountainous area, a radio station communication solution (i.e., not dependent on commercial service) is preferable. The sensor module is composed of a magnetic sensor chip capable of measurement in the x, y and z axes and its amplifying and filtering circuits.

The sensor is designed to be independent of the disturbance coming from the power supply of the monitoring unit by separating it from the main board. The entire system can be powered by a solar power module which is composed of a solar panel, a charger, and a battery, or alternatively, it can be powered through coupling with the transmission lines.

For the long span, an additional monitoring terminal can be added in the middle since the devices of a terminal are cheap and they can work at a place far away from the current-carrying conductors. The data collected from the remote monitoring terminals can be visualized in client software with the aid of the geographical information system (GIS) to help the operating crew locate the fault position promptly.

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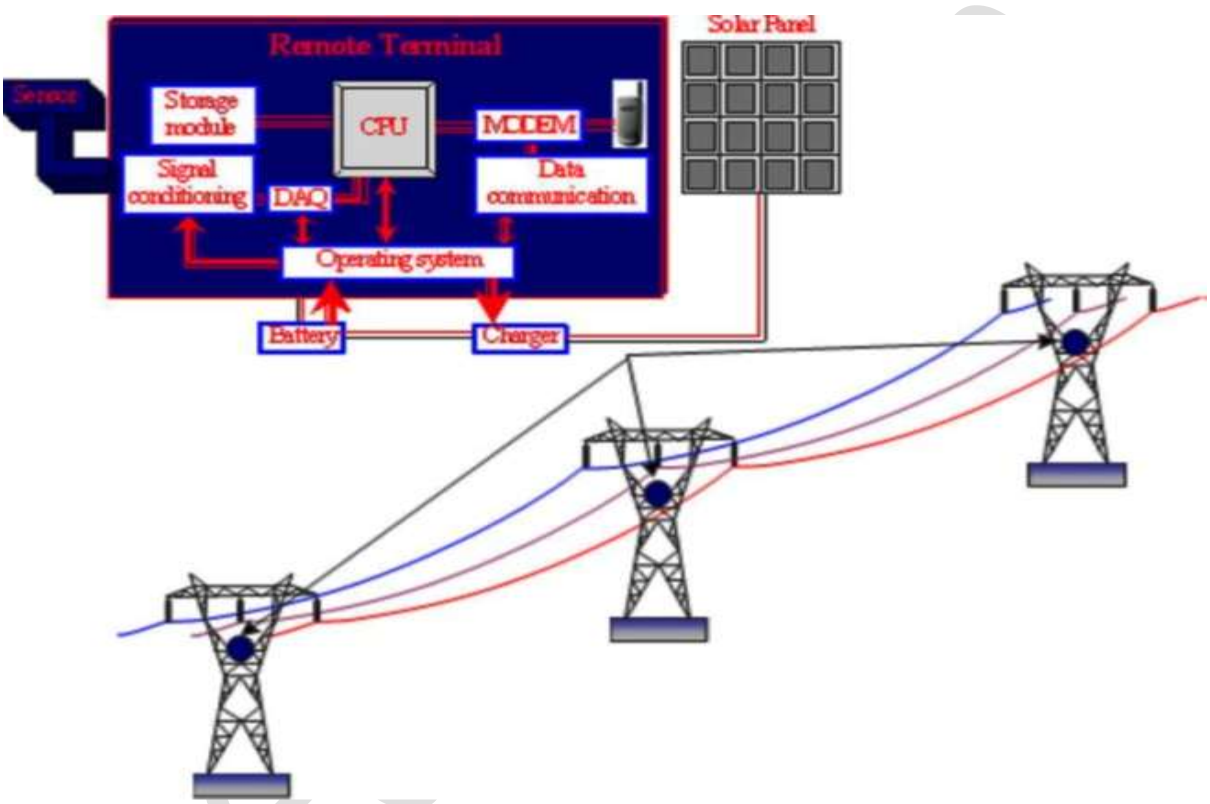


Overall scheme of the proposed solution for fault location in HV transmission lines. (The circles indicate the positions of sensors.)

6.1 3-D VECTOR MAGNETIC FIELD

The three components of the magnetic field in the 3-D space can be separately measured by MR sensors, they can be used to derive the change in the three-phase current. The magnetic field of current-carrying transmission-line conductors can be calculated by Maxwell's equations. Under certain assumptions, an analytical expression about the relative position between the measured point and the conductors can be formed.

$$\vec{B} = \hat{\iota_x} B_x + \hat{\iota_y} B_y + \hat{\iota_z} B_z$$

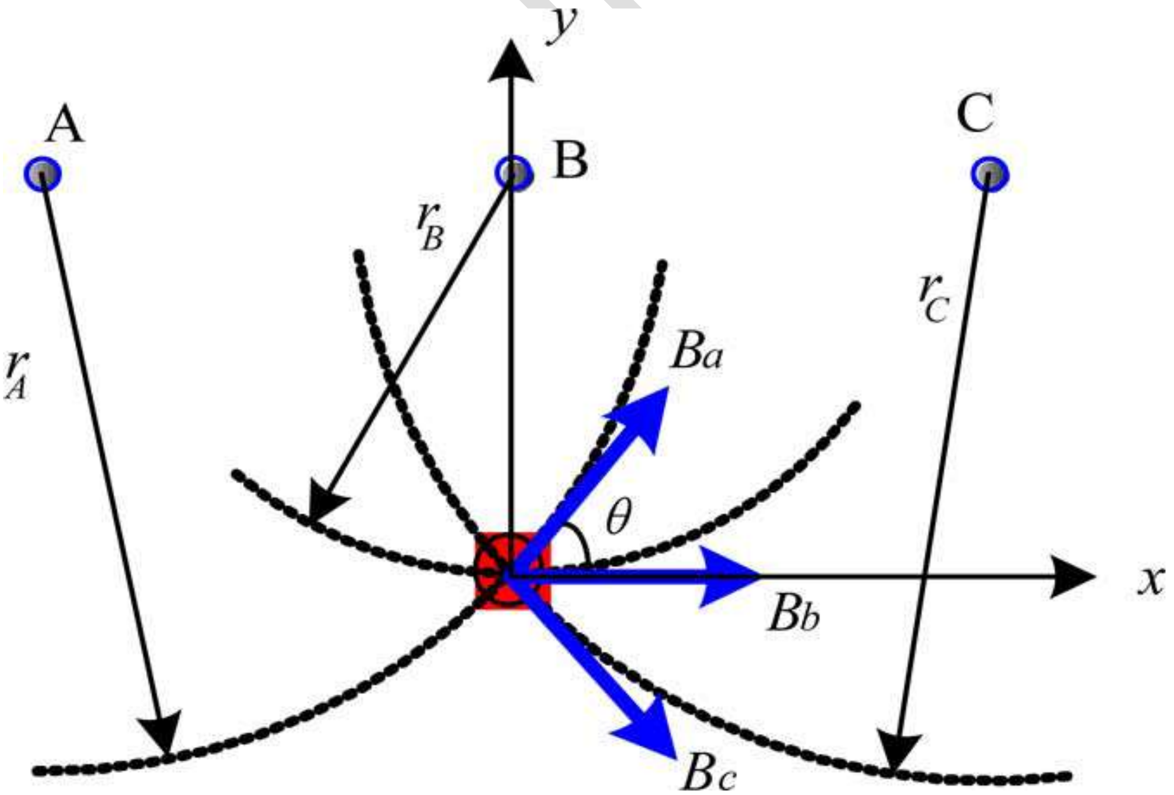
$$= \hat{\iota_x}(B_b + (B_a + B_c)\cos\theta) + \hat{\iota_y}((B_a - B_c)\sin\theta) + \hat{\iota_z} 0$$

Where B_x, B_y and B_z are the magnetic-field components generated by phase currents i_A, i_B and i_C respectively, and i_x, i_y and i_z are the unit vectors along the x, y and z axes respectively.

If the system is not symmetric, the magnetic field should be calculated according to the Biot–Savart law. However, for simple estimation, the effect of conductor sag is neglected and the line is assumed to be of infinite length, then B_a, B_b and B_c can be calculated as

$$B_a = \frac{\mu_0 i_A}{2\pi r_A} \qquad B_b = \frac{\mu_0 i_B}{2\pi r_B} \qquad B_c = \frac{\mu_0 i_C}{2\pi r_C}$$

where is the magnetic constant, and r_A, r_B and r_C are defined in Figure below



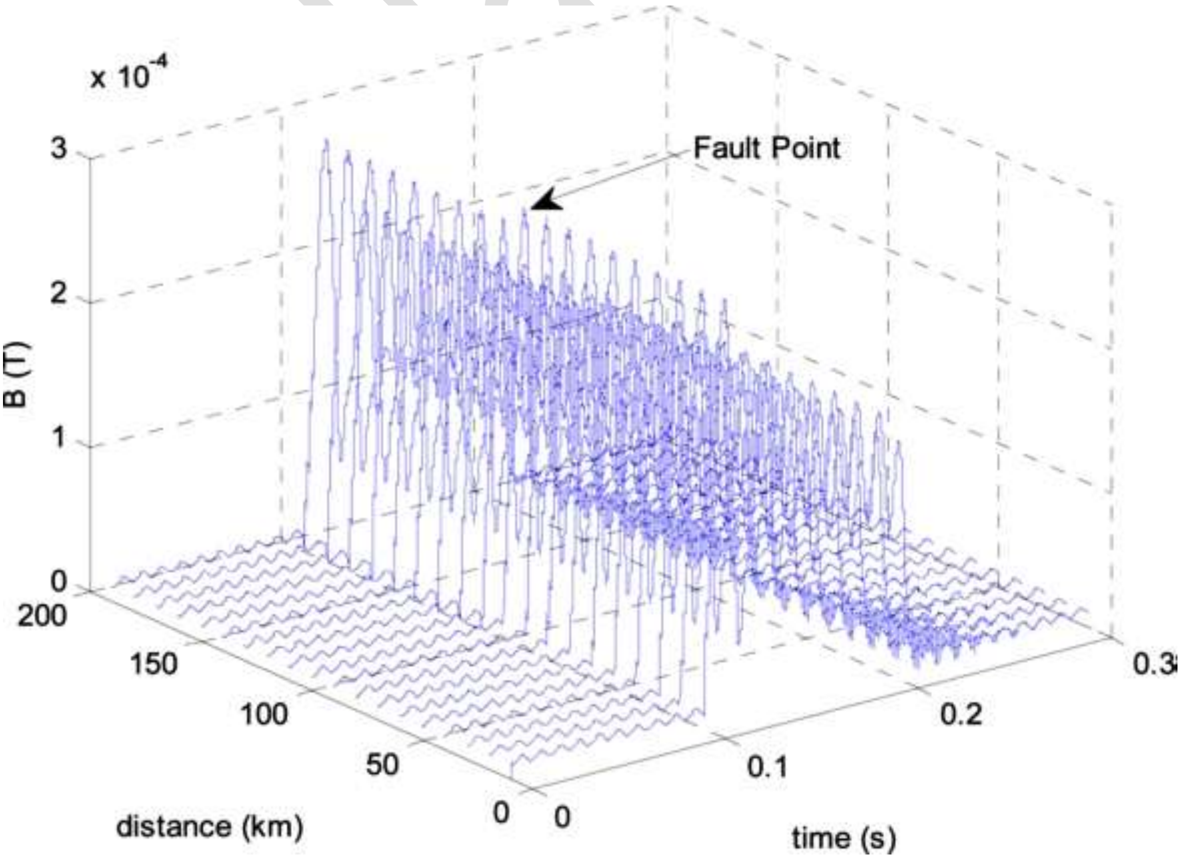
Calculation of the magnetic field at the point of sensor head. The direction of current is assumed to be along the z-axis, which is pointing toward the observer.

For a radial transmission system, in which only the sending end has power sources, it is simple to locate the fault point by simply checking where short-circuit current exists in the transmission lines. The output of the terminal closest to the fault point can only be used for qualitative analysis because its output may be affected by the fault.

CHAPTER 7
LOCATION OF FAULT

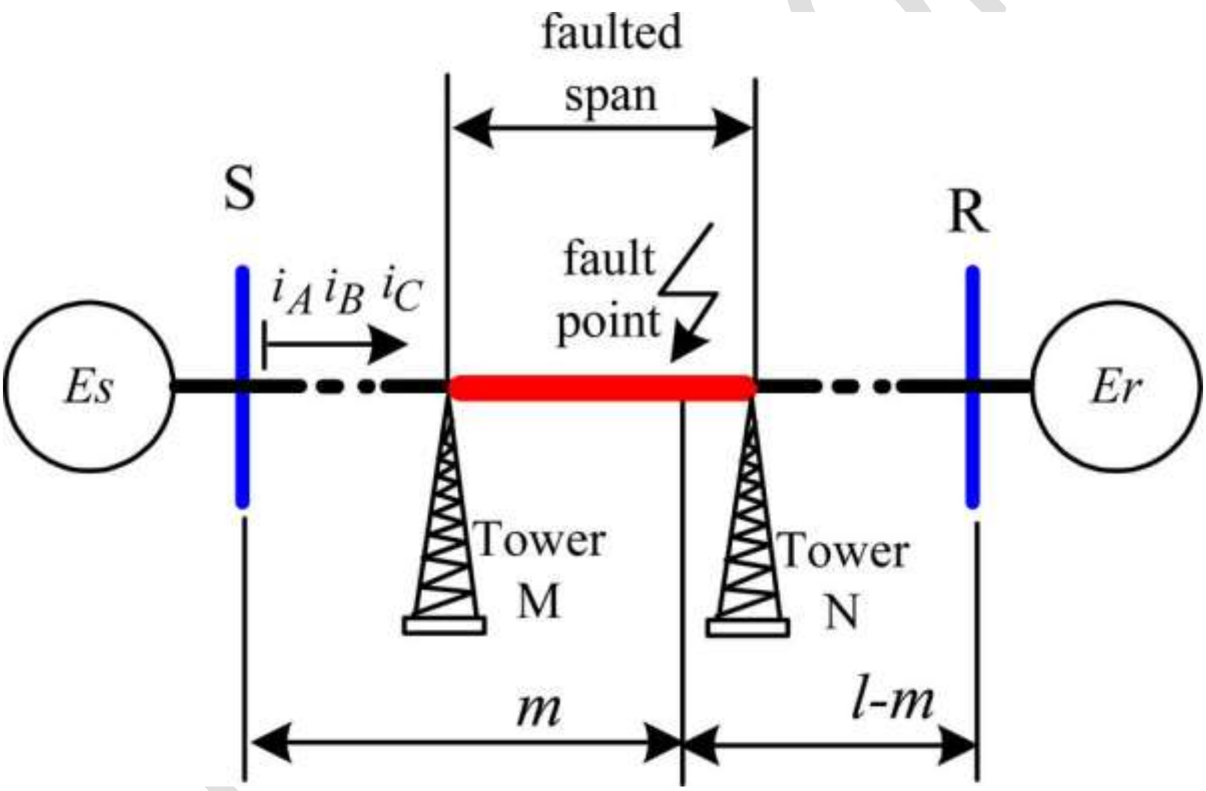
Typical faults on transmission lines include single-phase short circuit, double-phase short circuit, and three- phase short circuit. In the impedance-based approach, the effect of the fault resistance and ground resistance must be considered. In the proposed scheme, these effects do not affect the accuracy of the location.

When the three-phase short circuit occurs, the measured magnetic field is increased. The ratio of the magnetic field during the fault to that during the normal situation is the same as the ratio of the short-circuit current to the current at normal condition, provided that the transient process is not considered. The transient generally further increases the value of the magnetic field. In order to obtain a full view of the transient process along the entire transmission line to help find the fault point, the magnetic field measured at every tower along the transmission line, which connects two systems, is plotted



Distribution of the magnetic field along the transmission line under3-φ short-circuit condition (m =100 km).

In the figure, the axis represents the evolution of time (during the lifecycle of a fault, that is, prefault, fault, and postfault), the axis represents the distribution along the transmission line (0 to the length of the line), and the axis represents the measured magnetic field. Note that the high magnitude at the beginning of the fault is caused by the decaying dc components in the three-phase currents. The magnitude of the magnetic field at steady state under fault condition is determined by the short-circuit levels of the two systems connected at two sides. The difference in the short-circuit level can help locate the fault to a span by simply comparing the value of the measured magnetic field. If the fault occurs at a point where the short-circuit level at two sides is almost the same, making the magnitude of the magnetic field at two sides very close, then the direction of the magnetic field may be a good indicator of determining the fault span in this case.



System diagram of the test system in the numerical simulation (l: the total length of the transmission line and m: distance from the sending end to the fault location).

CHAPTER 8

IDENTIFICATION OF THE FAULT TYPE

The measured magnetic field can be used for not only locating the fault but also for identifying the fault type. When a fault occurs, the type of fault can be identified according to the magnitude and direction of the measured magnetic field. Since the short-circuit current is generally much larger than the normal current, the magnetic field caused by current flowing in the unfaulted phase can be neglected.

8.1 LINE TO GROUND FAULT

When a single-phase fault occurs, the measured magnetic field satisfies the following conditions

$\frac{B_y}{B_x} \approx \frac{\sin\theta}{\cos\theta} = \tan\theta$	fault at phase A
$B_y = 0$	fault at phase B
$\frac{B_y}{B_x} \approx \frac{-\sin\theta}{\cos\theta} = -\tan\theta$	fault at phase C

8.2 LINE TO LINE FAULT

When a double-phase fault occurs, one should distinguish the difference between line-to-line fault and double-line-to-ground fault. When the line-to-line fault is considered (transient neglected), the relation among the measured magnetic-field components

$\frac{B_y}{B_x} \approx \frac{\frac{1}{r_A}\sin\theta}{\frac{1}{r_B}+\frac{1}{r_A}\cos\theta}$	AB line to line fault
$B_x = 0$	AC line to line fault
$\frac{B_y}{B_x} \approx \frac{-\frac{1}{r_C}\sin\theta}{\frac{1}{r_B}+\frac{1}{r_C}\cos\theta}$	BC line to line fault

8.3 DOUBLE LINE TO GROUND FAULT

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When a double-line-to-ground fault occurs, there is no such simple relation among the components. However, by incorporating the estimation of the short-circuit current (since the fault point is known), the fault type can be identified.

In double line-to-ground fault the field strength is medium.When double phase line-to-ground fault occurs

1) AB line to ground fault - By is 1/√3 of that in three phase fault and By/Bx> 0
2) AC line to ground fault - By is as large as in three phase fault
3) BC line to ground fault - By is 1/√3 of that in three phase fault and By/Bx < 0

8.4 THREE PHASE FAULT

When three phase faults occurs, there is no such simple relation among the components. In the case of three phase fault all the magnetic components and field strength are large

8.5 FAULT IDENTIFICATION PROCEDURE

The identification procedure may consist of the following steps

1) Locating the fault according to the data sent back from the terminal installed along the transmission line
2) Approximately estimating the short-circuit current level with the fault distance determined by Step 1)
3) Comparing the measured magnetic field and the calculated value to determine whether the fault belongs to single-phase fault, double-phase fault, or three-phase fault
4) Further determine the actual type of the fault.
5) Locating within the fault span according to the result of previous location and identification

CHAPTER 9

LOCATION WITHIN FAULT SPAN

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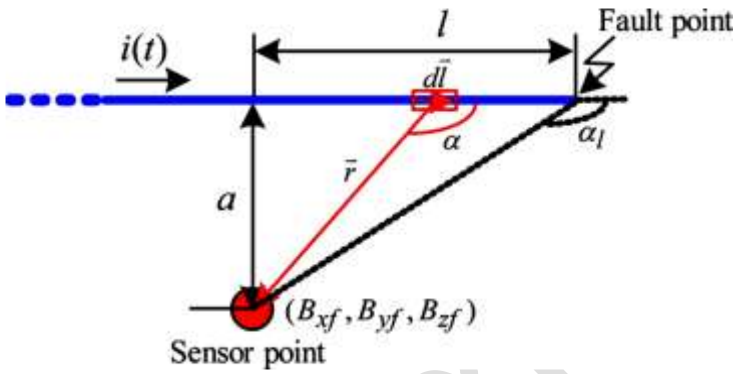
The fault span can be obtained by the earlier steps. It is observed that the measured magnetic fields have no significant difference along the faulted transmission line. However, the measured magnetic fields at the two sides of the fault span are different. This difference can be used to estimate the distance between the fault point and the tower. Figure



shows the model for estimation of the distance to a tower in a faulted span for a single conductor. Assuming that the sensor is installed under a faulted conductor on which a current i(t) is flowing through at a distance of a. If a is far less than the length of a span, according to Biot-Savart law, the ratio of the measured magnetic field beside the fault point to the other measured magnetic field is

$$\frac{B_{xf}}{B_x} = \frac{B_{yf}}{B_y} = \frac{1-\cos\alpha_f}{2}$$

Where Bx and By are assumed to be the measured magnetic field components far away from the fault span.

For double-phase and three-phase faults, it is more complex because a simple analytical expression cannot be found due to the difference in phase angle in the three phases. However, once the type of the fault is determined, the location within the fault span can be accomplished using the B_x or $B_y$component

CHAPTER 9

CONCLUSION

As the MEMS packaging technology and magnetoresistance material technology are progressing rapidly, MR sensors based on the magnetoresistance effect, which can carry out the point measurement of the magnetic field, may bring revolutionary change for measurement techniques in power systems. In this, a novel approach based on the noncontact measurement of magnetic field is proposed for the fault location of overhead transmission lines. By checking whether the short-circuit current exists in the transmission line at the position of an installed monitoring terminal, the fault span can be located which may greatly reduce the uncertainty in searching for fault location and, hence, improve the efficiency. Moreover, the solution is low-cost and more effective for finding the exact fault location even for non-permanent faults. After the fault span is located, the measured magnetic field can be used to further identify the fault type and locate within the fault span. In future, other types of tower configurations or their combinations should be considered to extend the applications. Moreover, the configuration of the sensor array can be further modified and improved in order to extend the application into the fault location for double or multi-circuit transmission lines.

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