Power transmission line fault location system

by Mark Edwin Lund

A thesis submitted in partial fulfillment of the requirements for the degree of Master of Science in Electrical Engineering
Montana State University

Abstract:
Power companies want to minimize power outage time since it is an inconvenience to customers and results in lost revenue. The time it takes to restore power after a fault depends upon quick and accurate fault location. Errors in fault location distance from ten to twenty percent of line length are common with the existing methods.

This thesis demonstrates the feasibility of a fault location system which detects and locates phase to ground and phase to phase faults at the supporting structures of an overhead power transmission line. A Fault Detector is placed on each tower of the transmission line. The direction of fault current in the static wire is used to determine fault location for transmission lines with grounded static wires. The magnitude of current flow in the tower is used to determine fault location for transmission lines with insulated static wires. When a fault occurs the Fault Detector at the faulted tower reports the fault location to a control room. Linemen are then dispatched to the faulted tower to correct the problem.

The feasibility of the fault detection scheme is demonstrated by the results of staged fault tests. Two types of Fault Detectors were built and tested. Both types of Fault Detectors were tested on a scaled model transmission line in Ryon Laboratory at Montana State University and on a low tension transmission line on the Montana State University campus. Additionally, the system detected and located staged phase to ground and phase to phase faults conducted on 100 KV and 115 KV transmission lines. A proposed 500 KV transmission line staged fault test is also outlined.

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Mark Edwin Lund

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Approved for the College of Graduate Studies

January 21, 1992 — Date

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Signature Mark E. Lund

Date January 9, 1992

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TABLE OF CONTENTS

TABLE OF CONTENTS - Continued

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Power companies want to minimize power outage time since it is an inconvenience to customers and results in lost revenue. The time it takes to restore power after a fault depends upon quick and accurate fault location. Errors in fault location distance from ten to twenty percent of line length are common with the existing methods.

This thesis demonstrates the feasibility of a fault location system which detects and locates phase to ground and phase to phase faults at the supporting structures of an overhead power transmission line. A Fault Detector is placed on each tower of the transmission line. The direction of fault current in the static wire is used to determine fault location for transmission lines with grounded static wires. The magnitude of current flow in the tower is used to determine fault location for transmission lines with insulated static wires. When a fault occurs the Fault Detector at the faulted tower reports the fault location to a control room. Linemen are then dispatched to the faulted tower to correct the problem.

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CHAPTER 1

INTRODUCTION

Reliability of overhead transmission lines is a top priority of power companies. Customer outage results in lost revenue and disruption of service. If the fault is found quickly and accurately, the cause can more likely be determined.

Background

Traditionally, faults in overhead circuits are located by isolating sections and exposing the system to repeated close-ins. Linemen visually inspect the isolated sections for the fault. Helicopters are sometimes used to decrease the inspection time.

Fault indicators may be employed to help identify where the fault exists. One type of indicator placed on the static wire uses two magnets. Fault current demagnetizes one magnet causing a red flag to show. The flag is held in this position by the other magnet until a lineman resets the indicator. The trip current is set at the factory. Many of these indicators on towers on each side of the faulted tower may trip if the fault current is higher than the trip current rating. Also, none of the indicators may trip if the fault current is smaller than the trip current rating. Confusion may occur on the location of the present fault if all the indicators were not reset after a previous fault [1]. Other indicators of this type reset automatically after a specified amount of time.

Another type of indicator clamps directly around the high voltage conductor. It senses both line current and voltage. The simultaneous presence of line voltage and a stepped increase in current triggers the unit [2].

Faults can also be located by using traveling wave time intervals from the fault. Electronic clocks at each side of a line section record the exact time a traveling wave from the fault reaches its terminal. The fault is located by the incremental difference in time between the clocks. This method requires the clocks to be precisely synchronized. This is accomplished with a microwave link. A major source of error for this system is the variation in travel time over the communications link [3].

Another technique of locating faults is the Oscillograph and Fault Study Analysis Method. This method uses a model of the power system as fault study program data. A fault on the line section of interest is moved along the line (i.e. a sliding fault) until the magnitude of the current obtained from the fault study equals that measured on the oscillograph [3].

Schweitzer Engineering Laboratories has developed a relay, SEL-21, which provides fault location. The relay continually monitors voltage and current at one line terminal. Pre-fault and post-fault data are processed using the Takagi algorithm to determine the location of the fault [4,5].

Power companies want the location of the fault more accurately and sooner than these methods can provide. This thesis investigates fault location based upon direction of fault current in the static wire and also based upon magnitude of fault current in the faulted tower.

Fault Location System Design

This Fault Location System was designed based upon the following:

1. Determine fault location by

    i. direction of current flow in static wire for transmission lines with grounded static wires.

    ii. magnitude of current flow in tower for transmission lines with insulated static wires.

2. Factors such as power consumption and circuit optimization were given high priority.

3. Implement decision logic for identification of faults in software instead of hardware to increase accuracy. This also enables easy modification of the decision criteria.

4. Fault Detector on faulted tower transmits fault location by radio. Use an error correction code to increase the reliability of the transmitted information.

CHAPTER 2

FAULT LOCATION SYSTEM

Faults are classified into two types: phase to ground faults and phase to phase faults. Most faults, about 90 percent, are phase to ground faults. A phase to ground fault occurs when one of the phases is shorted to ground. A phase to phase fault occurs when either two or all three phase lines are shorted to one another. Faults are caused by insulator breakdown, fallen lines, foreign objects (e.g. trees hitting the lines), and other randomly occurring events. A phase to phase fault may also occur if high wind slaps the conductors together.

The system being developed locates phase to ground and phase to phase faults to the nearest support tower of an overhead transmission line. The system consists of Fault Detectors, Repeaters and a Control Room Monitor (Figure 1). A Fault Detector is installed on each tower of the transmission line. When a fault occurs the Fault Detector at the faulted tower transmits a message frame containing its unique Tower Identification Code. Repeaters relay the message frame to the Control Room Monitor at the power company's headquarters. The Monitor displays the Tower Identification Code of the faulted tower and other pertinent information.

The line configuration as discussed later dictates whether Type I or Type II Fault Detectors are installed. All the units on a single line must be of the same type. When a fault occurs the Fault Detectors near the fault are awakened by the fault

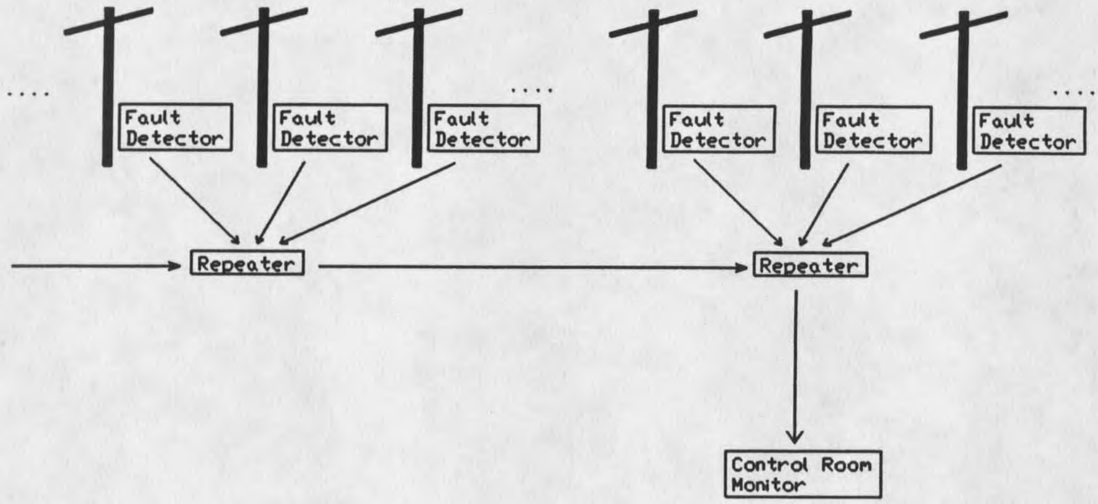

Figure 1. Fault Location System

current. The Fault Detectors receive information on the fault currents at their particular tower from their sensors placed on the static wire and/or on the tower itself. Type I Fault Detectors make a decision whether the fault occurred at the tower or not based on the direction of currents in the static wire. If the fault is at the tower, the Fault Detector transmits a message frame containing the Tower Identification Code and the type of fault. If the fault is at another tower no message frame is transmitted by the Fault Detector. Conversely, Type II Fault Detectors always transmit a message frame when activated by fault current. The transmissions from adjacent towers are staggered in time according to Tower Identification Code to prevent simultaneously transmitted frames from interfering with one another. The message frames contain the Tower Identification Code and a value proportional to the RMS value of fault current down the tower.

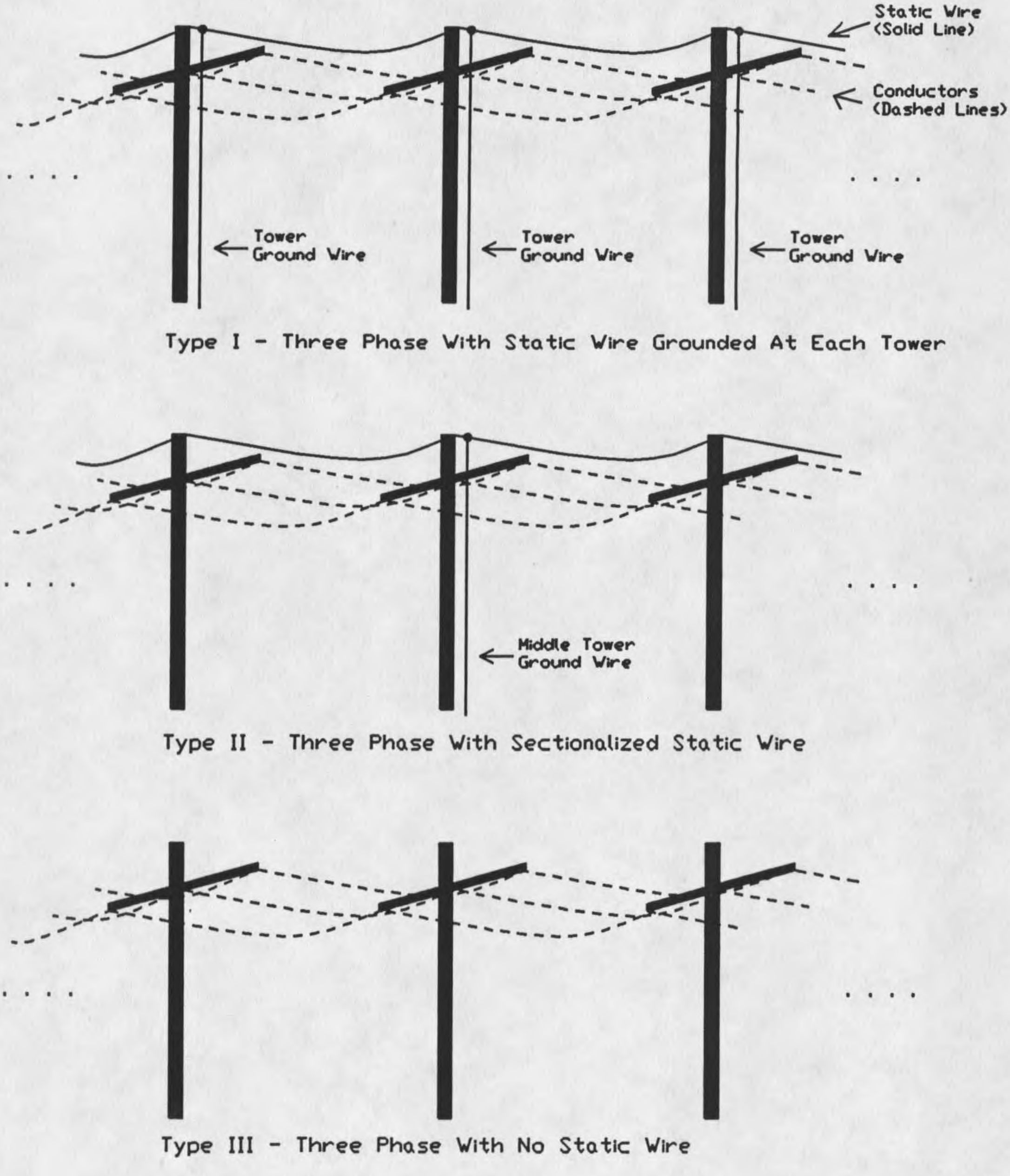

Figure 2. Power Transmission Line Configurations

Transmission Line Configurations

In this thesis, overhead power transmission lines are classified according to the arrangement of the static wire (Figure 2). In Type I line configuration the static wire is grounded at each tower by a tower ground wire. Type II line configuration is a sectionalized line in which the static wire is divided into segments (typically six miles long) that are insulted from one another. The middle of each of these segments is grounded by a tower ground wire. The segment is insulated from all other towers. Type III line configuration consists of no static wire. Type I Fault Detectors are installed on Type I transmission lines while Type II Fault Detectors are installed on Type II and Type III transmission lines.

Type I Line Configuration

Most overhead power transmission lines used by Montana Power Company are Type I configuration. Because of this, most of the work described in this thesis pertains to fault detection for Type I transmission lines.

Phase To Ground Fault Currents

Current flows away from the faulted tower through the static and tower ground wires during a phase to ground fault. The static and tower ground wires can be modeled as an impedance ladder network (Figure 3). The current splits according to the current divider rule. The current splits evenly if the impedances seen by the fault

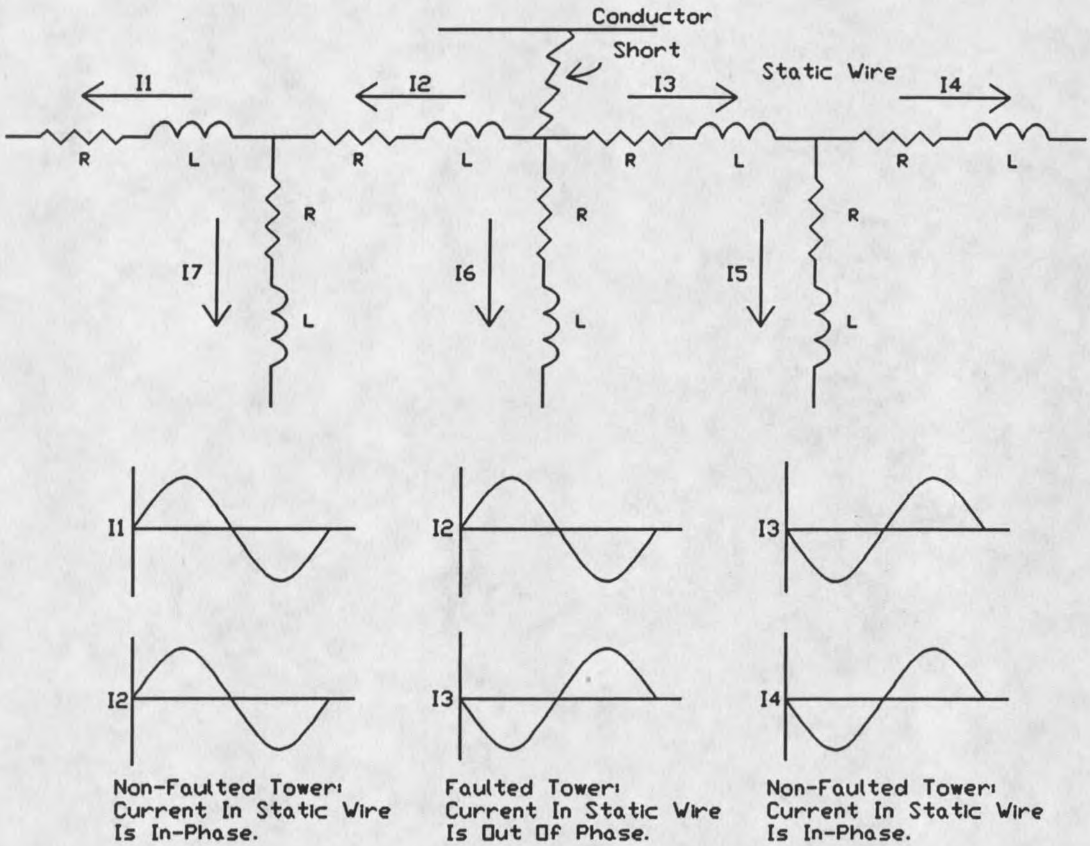

Figure 3. Type I Line Configuration Phase to Ground Fault Currents

current are equal on each side of the tower. In a realistic situation the impedances are not equal on each side of the tower. Differences in impedances are due to different ground resistances, poor connections, tower being at the end of the transmission line, etc. Unequal impedances cause more current to flow on one side of the tower than on the other side. If there is a large enough difference most of the current flows on one side of the tower and the current on the other side may not be distinguishable from noise present in the static wire. In either case the current in the static wire flows (1) in the same direction through the non-faulted towers and (2) in opposite direction at the faulted tower (Figure 3). Furthermore, the fault current in the static wire becomes less farther away from the faulted tower due to current flow to the ground at each grounded tower to which the static wire is connected.

Static Wire Current Sensors

Current sensors are placed around the static wire on each side of the tower to sense the fault current direction. The current sensor consists of a secondary winding wrapped around a ferromagnetic ring. The static wire runs through the center of this ring and acts as a primary winding (Figure 4). The current sensor design allows only

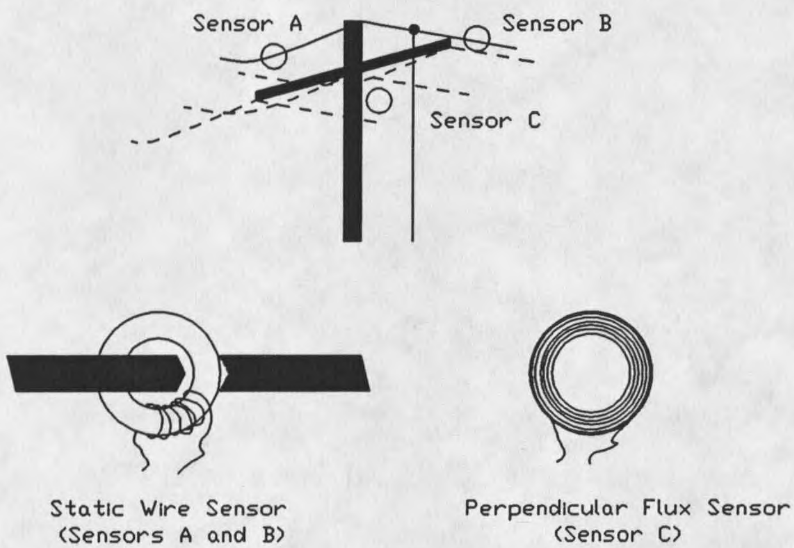

Figure 4. Type I Line Configuration Current Sensors and Their Placement

the current in the static wire to develop a voltage on the secondary terminals. Flux produced by current outside of the ring will not develop a voltage on the secondary terminals of the sensor.