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ABSTRACT

FAULT LOCATION ON TRANSMISSION AND DISTRIBUTION LINE

By

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Master of Science in Electrical Engineering

Fault location is one of the most critical issues of utilities and electrical companies in today’s competitive market. Analysis of fault location not only ensures the continuous power supply but also help to study properties and weakness of particular power network. In the following paper, I have discussed various traditional and new approaches to fault location. Also I have done Matlab simulation to prove the accuracy of the algorithm. I have used fundamental frequency component of fault voltage and current for the analysis.
1. Fault location

1.1 Introduction

Fault location is a procedure projected at locating the occurred fault with the highest possible accuracy. A fault locator is mostly additional protection equipment, which apply the fault-location algorithms for assessing the distance to the fault. [1]

A fault-location function can be implemented into:

- Microprocessor-based protective relays;
- Digital fault recorders (DFRs);
- Separate fault locators;
- Post-fault examination programs.[4]

“Protective relays are narrowly correlated with fault locators; however, there are some alterations between them which can be considered as related to the following features

- Correctness of fault location;
- Speed of defining the fault position;
- Speed of spreading data from the remote site;
- Used data window;
- Digital filtering of input signals and difficulty of calculations.”[1]

“Fault locators are used for identifying the fault position correctly and not only for warning for the general area (defined by a protective zone) where a fault occurred which is the case for protective relays.” One of the crucial requirements imposed on the protective relays is speed of operation. The faulted line has to be cut off from the main grid as soon as possible to prevent the spreading of fault effect. “Therefore, high-speed measuring algorithms are applied in contemporary protective relays. The use of high-speed operating circuit breakers is also of prime importance. Fault-clearing time is an important consideration in the selection of protective relays and requirements for relaying speed must be determined carefully. System instability, excessive equipment damage, and adverse effects on customer service may result, if the relaying is too slow. While faster protection will lead to negotiate relay system security and selectivity.” “The requirement for the fast clearing of faults demands that the decision for tripping transmission lines has to be made in a short time, even faster than in one cycle of the fundamental frequency (for the systems operating at 50 Hz it will be 20ms). On the other side, the analysis of fault locators are performed in an off-line mode since the results of these calculations (the position of the fault and in the case of some algorithms also the involved fault resistance) are for human users. This implies that the fault-location and speed of calculations can be measured in seconds or even minutes. Low-speed data communications or supervisory control and data acquisition (SCADA) can be applied for fault-location purposes, which differ from communication used by protective relays. The best data window segment from the whole available window can be selected for the fault location to reduce errors. This is so since the computations are performed in an off-line.
regime and searching for the best data window can be easily applied.” The fault interval lasts from fault incipience up to a fault clearing by a circuit breaker, and usually this takes around three fundamental frequency cycles, which is wider than required for the fault location. In the case of the protective relays the required high speed imposes that applied calculations should not be too complex and too time consuming. In contrast, fault-location calculations do not have such limitations. As for example, rejection of DC components can be applied for more accurate phasor analysis of the fault location. Also, models of power lines and faults in fault-location algorithms are usually more advanced than the computational capacity of microprocessor relay. Among different types of relays commonly used for protecting power lines, distance relays are the most related to fault locators. “When fault is identified as occurring within the pre-defined protective zone, then a trip signal to the corresponding circuit breaker is sent immediately. In consequence, the fault becomes isolated quickly, which minimizes the impact of a fault on a power network. Distance relays have multiple protection zones to provide back capability. The relay that detects the fault in the 1st-zone is designed to trip first. Generally, a pair of distance relays is used to protect a two-terminal line. Usually, they communicate among them, creating a pilot relaying. As a result of exchanging information between the distance relays from the line terminals, they both could trip at the 1st-zone setting. Operation of a distance relay may be significantly influenced by the combined effect of fault resistance with load, which is also called as the reactance effect. The distance relay may mis-operate for a forward external fault, or may not operate for an internal fault if the value of the fault resistance is too large. The value of the fault resistance may be particularly large for ground faults, which are the most frequent faults on overhead lines.”[1][4][5][6].

1.2 General Division of Fault-location Techniques

Fault location is possible in a natural way by foot patrols or by tech persons equipped with different conveyance means and binoculars. These means of faulted-line inspection is considered as time consuming. The method of fault location involved optical inspection as is mentioned. Also, calls from witnesses of harms on the power line, or client calls, can deliver the required knowledge about the fault position. However, such simple ways do not fulfill the necessities imposed on fault location [2]. Valued information on fault location can be gotten also from fault indicators; they are installed either in substations or on poles (or towers) along the transmission or distribution line. Additional use of a radio link allows use of the info from indicators also during bad weather. In spite of several efforts to dissimilar unusual techniques, automatic fault location is still famous and most widely used. It is based on determining the physical location of a fault by analyzing the voltage and current waveform values. Automatic fault location can be classified into the following main categories:

- “fundamental-frequency of currents and voltages, impedance measurement”
- “traveling-wave”
- “high-frequency components generated by faults” [2][3][6]
1.3 Input Signals of Fault Locators

Mostly, the fault voltage and current are used for the fault location. However, pre-fault quantities may also be used in many fault-location approaches. But usage of the pre-fault data is treated as the drawback of the fault-location technique. [2][3][6]

1.4 Influencing factors on Fault-location accuracy

Following are the factors that may influence

- “Inaccurate compensation for the reactance effect”
- “Inaccurate fault-type (faulted phases) identification”
- “Inaccurate line parameters, which do not match the actual parameters.”
- “Uncertainty about the line parameters”
- “Inaccurate compensation for the mutual effects on the zero-sequence Components”
- “Insufficient accuracy of the line model”
- “Presence of shunt reactors and capacitors”
- “Load-flow unbalance”
- “Errors of current and voltage instrument transformers”
2. Traveling wave technique

2.1 What is traveling wave?

“Fault causes transients that propagate along the transmission line as waves. This wave can have frequencies, ranging from a few kilohertz to several megahertz, having a fast rising front and a slower decaying tail. They have a propagation velocity and characteristic impedance and travel near the speed of light away from the fault location toward line ends.” [7] They continue to travel throughout the power system until they die due to impedance and reflection waves and new power system equilibrium is reached. “The location of faults can be precisely time-tagging wave fronts as they cross a known point typically in substations at line ends. With waves, time tagged to sub microsecond resolution of 30 m, the fault location accuracy of 300 m can be obtained. Fault location can then be obtained by multiplying the wave velocity by the time difference in line ends. This collection and calculation of time data is usually done at a main station. Main station information polling time should be fast enough for system operator needs”. [7]

2.2 Benefits of Traveling Wave Fault Location

- “Uses reflected radar energy to determine the fault location”
- “Technique is popular for location of permanent faults on cable sections when the cable is de-energize”
- “Provide algorithm advances that correct for fault resistance and load current inaccuracies. Line length accuracies of ±5% are typical for single-ended locators and 1-2% for two-ended locator systems”
- “Higher accuracy, Long lines, difficult accessibility lines, high voltage direct current (HVDC), and series-compensated lines are popular applications”
- “Accuracies of <300 meters have been achieved on 500 kV transmission lines with this technique”

2.3 Traveling Wave Fault Location Theory

![Diagram of traveling voltage and current waves]
The differential equation for a transmission line at any point

\[
\frac{\partial e}{\partial x} = -L \frac{\partial i}{\partial t} \quad \text{and} \quad \frac{\partial i}{\partial x} = -C \frac{\partial e}{\partial t} \quad \text{………………………… 2.1}
\]

where \( L \) and \( C \) are the inductance and capacitance of the line per unit length. The resistance is assumed to be negligible. The solutions of these equations are

\[
e(x,t) = e_f(x-\nu t) + e_r(x+\nu t) \quad \text{………………………… 2.2}
\]

\[
i(x,t) = \frac{1}{z}e_f(x-\nu t) - \frac{1}{z}e_r(x+\nu t) \quad \text{………………………… 2.3}
\]

Where \( z = \frac{\sqrt{LC}}{\nu} \), the characteristic impedance of the transmission line and \( \nu = \frac{1}{\sqrt{LC}} \) is the velocity of propagation. [7]
3. Single Ended Method

Single ended algorithm calculates the fault location using apparent impedance from one end to the fault. We need to measure phase to ground voltages and current in every phase to locate the fault type in this algorithm. If we have only line to line voltages, we can locate phase to phase faults and if we know zero sequence source impedance, finding the location of phase to the ground faults is possible.

The following table gives the fault location for different types of fault. Here fault resistance is assumed to be zero.

<table>
<thead>
<tr>
<th>Type of fault</th>
<th>Impedance equation to calculate the fault location ( m Z\textsubscript{1L})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ground – phase a</td>
<td>V\textsubscript{A} ( I\textsubscript{A} + K I\textsubscript{R} )</td>
</tr>
<tr>
<td>Ground – phase a</td>
<td>V\textsubscript{B} ( I\textsubscript{B} + K I\textsubscript{R} )</td>
</tr>
<tr>
<td>Ground – phase a</td>
<td>V\textsubscript{C} ( I\textsubscript{C} + K I\textsubscript{R} )</td>
</tr>
<tr>
<td>Phase a – phase b or a – b – ground</td>
<td>V\textsubscript{AB} / I\textsubscript{AB}</td>
</tr>
<tr>
<td>Phase a – phase b or a – b – ground</td>
<td>V\textsubscript{BC} / I\textsubscript{BC}</td>
</tr>
<tr>
<td>Phase a – phase b or a – b – ground</td>
<td>V\textsubscript{CA} / I\textsubscript{CA}</td>
</tr>
<tr>
<td>Phase a – phase b – phase c</td>
<td>Any one of above three</td>
</tr>
</tbody>
</table>

Table 3.1 Equations for simple impedance [3]

Where in the above table, K is \( \{[Z\textsubscript{0L} - Z\textsubscript{1L}] / 3Z\textsubscript{1L} \} \) which is the ratio of difference zero sequence line impedance and positive sequence line impedance to positive sequence line impedance. Also m is the per unit distance from the fault which is nothing but distance from fault divided by the total length of the line.

Current and voltage values are used to calculate the impedance of the fault location as shown in the above table. If we have the value of line impedance per unit, distance in per unit can be easily calculated. [3][8]

3.1 Factors which affects the fault location calculation

There are many factors which may affect the fault location estimation. Some of them are as following.

1. Reactance effect, it is combined effect created by load current and fault resistance. This value is really high in case of ground fault which is actually representing the majority of the fault types.
2. Wrong fault identification
3. Zero sequence mutual effect
4. Uncertainty in zero sequence impedance
5. Line model insufficient accuracy
6. Shunt reactors and capacitors
7. Unbalance load flow
8. Measurement errors

It is important to reduce these factors in order to improve the fault location estimation. [3][8][9]

3.2 Equipment and the input data required

This method may require the following equipment to abstract the data from a system for calculation

1. Microprocessor based relays
2. SCADA interface

Following would be the data above instruments provide for the successful estimation

1. Phase to ground voltages and phase current
2. Type of fault occurred
3. Pre fault data may be needed sometime [3]

3.3 Fault resistance and load

Let us consider the simple single line diagram to find out the issues for calculation, the location of fault using one end data.

Fig 3.1 One line and equivalent ckt for a 3 phase transmission line fault [3]
Line between terminals G and H in the above fig is a homogeneous line with an impedance $Z_L$. $R_F$ is the fault resistance. $V_G$ and $V_H$ and the voltages at the respective terminal while $I_G$ and $I_H$ represents the current from the respective ends which will contribute to the final fault current $I_F$. $Z_G$ and $ZF$ would be source impedances.

Voltage drop from terminal G can be expressed as follows

$$V_G = mZ_LI_G + R_HI_F$$  \[3.1\]

If we divide the above equation by the current $I_G$, we will get the value of impedance measured at terminal G.

$$Z_{FG} = \left(\frac{V_G}{I_G}\right) = mZ_L + R_F\left(\frac{I_F}{I_G}\right)$$  \[3.2\]

$Z_{FG}$ in the above equation is the apparent impedance to the fault which is measured at terminal G.

The ratio of fault current and current at the fault locator ( $I_F$ and $I_G$ ) will be a complex number. Therefore the fault resistance will be impedance with the reactive component in it. It depends on the angle of the ratio of two current that if the reactive component is inductive or capacitive. It can be zero, when there is no infeed current from the remote terminal, or it is in phase with local current.

![Diagram](image)

**Fig 3.2 Fault resistance of fault resistance and pre fault load errors [3]**

To find out the parameters which affects the angle of $I_F / I_G$, we can separate pre-fault and fault system (Superposition). If $I_L$ is pre-fault load current and $\Delta I_G$ is the difference or superimposed current then we can write equation 3.2 as
\[ Z_{FG} = \frac{V_G}{I_G} = m Z_L + \frac{1}{d_s n_s} \] \hfill (3.3)

Where \( d_s \) is the current distribution factor

\[ d_s = \frac{\Delta I_G}{I_F} = \frac{Z_H + 1-m Z_L}{Z_H + Z_L + Z_G} = d_s \angle \beta \] \hfill (3.4)

And \( n_s \) is the current loading factor

\[ n_s = \frac{I_G}{\Delta I_G} = \frac{I_G}{I_G - I_L} = n_s \angle \gamma \] \hfill (3.5)

These two factors will determine the reactive component caused by fault resistance. We need to reduce the effect of fault resistance \( R_F \). 

3.4 Different single end method algorithms

Different fault location can be used depending on the circuit data available. Following are some of them

1. Simple Reactance method

This method assumes that the fault resistance current and current at the measurement side is in the phase. In this case device will measure the apparent impedance and then will find the ratio of the measured reactance to the reactance of the entire line.

In this algorithm, fault resistance is compensated by measuring only apparent line impedances imaginary part.

\[ m = \left. \frac{V_G}{I_G} \right|_{Z_L} \] \hfill (3.6)

Also for line to ground fault, it would change as follows

\[ m = \left. \frac{V_G}{I_G + K_o I_R} \right|_{Z_L} \] \hfill (3.7)

If the fault reactance is zero or \( I_C \) is in the phase with \( I_F \), error will be zero. This algorithm will give considerable error if the fault has high resistance. [3][8]
2. Algorithm of fault location without using source impedance

This method uses superposition current $\Delta I_G$. Equation 3.1 can be written as follows to represent the voltage drop across the fault resistance $R_F$.

$$V_G = m Z_{IL} I_G + R_F \Delta I_G / d_s \quad \ldots \ldots \ldots \ldots 3.8$$

Let’s multiply both side by complex conjugate of $\Delta I_G$ i.e. $\Delta I_G^*$.

$$V_G \Delta I_G^* = m Z_{IL} I_G \Delta I_G^* + R_F / d_s \quad \ldots \ldots \ldots \ldots 3.9$$

So if a system is homogeneous fault location can be given as

$$m = \frac{l_m (V_G \Delta I_G)}{l_m (Z_L \Delta I_G)} \quad \ldots \ldots \ldots \ldots 3.10$$

Matlab simulation is used to prove the accuracy of this method later in the report. This method will work if fault current at the fault locator and fault current at fault are in phase. The error of this method is directly proportional to the $\sin \beta$ which varies with the fault distance and cannot at all calculate if source impedance is unknown. So the value of $\beta$ will be zero if the current is strong. This method removes circuit loading error. [3][9]

![Fig 3.3 Single line diagram form single ended fault location](image)

3. Algorithm of fault location using source impedance

This case requires the knowledge of source impedance which is in actual practice very hard to have with required accuracy. “If it’s known, the fault location can accurately achieve with desired level.” As “$d_s$” is the function of source impedance, line impedance and unknown fault distance $m$. It solves a quadratic equation.

$$m^2 - m k_1 + k_2 - k_3 R_F = 0 \quad \ldots \ldots \ldots \ldots 3.11$$
Where k1, k2, k3 are the complex function of local voltage current and source impedance respectively.

If we separate the above equation in an imaginary and a real part, per unit distance can be calculated. [3]
4. Double Ended Method

Present innovation takes into consideration utilization of information from both ends of the transmission line. The basic concept of locating faults using double ended method is similar as that of a single end method. In double ended method, we minimize the effect of fault resistance and other factors which affect the accuracy of fault location. Fault location using double ended method is more accurate than single ended method. In double ended method, we don’t need to recognize the type of fault in order to calculate the location of the fault. So rather than using zero sequence, we can use +ve sequence components which minimizes the effect of zero sequence components. The only drawback is it requires a mean of communication to gather the data of remote end whereas in the single end method line terminal, relay or devices collecting data is enough. Double ended method takes more time but it is quick enough to be used by a human. The response time is in seconds. We must synchronize the collected data from both the ends before starting analysis. [15][16]

4.1 Equipment and the input data required

Double ended method may require the following equipment to abstract the data from a system for calculation

1. Any device that gives 3 ph. voltage and current in each phase like Microprocessor based relays
2. Mode of Communication
3. Data collecting equipment or a tech person at the central site

Following would be the data above instruments provide for the successful estimation

1. Phase to ground voltages and phase current
2. Time correlation for phasor calculation. [3]

4.2 Common approach/ Algorithm

This method is commonly used and is as shown below. Let us consider a fault at distance m per unit, from the bus G and at a distance of (1-m) from the bus H. Let us denote the voltage at fault as \( V_F \), \( V_G \) is voltage at bus G, and \( V_H \) is voltage at H, \( I_G \) is current from bus G and \( I_H \) is current from bus H. Fault current \( I_F \) will be the sum of tow current. We can write voltage current relationship in all phases from fig. as follows.
\[(V_{GF})_{abc} = mZ_{Labc} (I_{GF})_{abc} + V_F \] .................................4.1

\[(V_{HF})_{abc} = (1-m)Z_{Labc} (I_{HF})_{abc} + V_F \] .................................4.2

4.1 One line diagram and equivalent ckt. For fault on line [3]

Subtracting 1 equation 4.1 and 4.2

\[(V_{GF})_{abc} = (V_{HF})_{abc} = mZ_{Labc} (I_{GF})_{abc} + (m-1)Z_{Labc} (I_{HF})_{abc} \] .................................4.3

Above equation will give us the value of m.

4.3 Algorithm used for Matlab

It was considered a single line to ground fault at a transmission line for double ended method algorithm. The reason for selecting single line to ground fault is it is most occurred fault on a transmission line. “Research data shows that amongst the entire fault more than 70% of the faults are single line to ground fault.” This method does not require any kind of knowledge of source impedance. And the fault location distance calculated is not influenced by the value of fault resistance. Also fault resistance can be evaluated from the knowledge of distance of the fault also the nature of the fault. [15][17]

The figure below shows the single line to the ground fault with the fault at a distance of m from substation A, and (1-m) from substation B. \(V_A\) and \(V_B\) are voltages at the substation \(V_F\) is the fault voltage, \(R_F\) is the fault resistance. The value of m is unknown. During fault on transmission line, current from both the substations will go in to the fault point and return back to the substation through ground fault. Therefore fault current \(I_F\) will be a summation of current from substation A and current from substation B. [15]
4.2 “Single line to ground fault condition” [15]

Single line to ground fault can be converted into its sequence components as seen from two substations.

4.3 “Network connection seen from substation A” [15]

Ground to phase fault voltage seen from substation A can be written as
\[ V_F = V_A - m (Z_1 + Z_2 + Z_0) \] \hspace{1cm} \text{4.4}

Similarly Ground to phase fault voltage seen from substation B can be written as

\[ V_F = V_B - (1-m) (Z_1 + Z_2 + Z_0) \] \hspace{1cm} \text{4.5}

Equating 4.4 and 4.5

\[ V_A - m (Z_1 + Z_2 + Z_0) = V_B - (1-m) (Z_1 + Z_2 + Z_0) \] \hspace{1cm} \text{4.6}

Also for both the substation phase current zero sequence current components are equal

\[ I_{A0} = I_A / 3 \] \hspace{1cm} \text{4.7}
\[ I_{B0} = I_B / 3 \] \hspace{1cm} \text{4.8}

Therefore from above equations, we can calculate the value of \( m \) as

\[ m = \frac{V_A - V_B + \left( \frac{I_B}{3} \right) (Z_1 + Z_2 + Z_0)}{\left( \frac{I_A + I_B}{3} \right) (Z_1 + Z_2 + Z_0)} \] \hspace{1cm} \text{4.9}
5. Fault Location on distribution Lines

5.1 Introduction

“The problem of fault location has been studied deeply for transmission lines and is revealing special attention mainly because of power quality regulations. Various methods have been discussed for the location of fault on distribution lines. But somehow these methods are not easily applicable to distribution systems because these use measures from two terminal lines, the non-homogeneity, presence of lateral and load taps on distribution lines.”[13]

Fault location techniques are classified in following different categories:

- Classical approach that measures fundamental voltage and currents.
- Traveling wave theory technique.
- Topological method approach.
- Knowledge based approach.

5.2 Different Approach

In this chapter we will review the classical approach and knowledge based approach and also a hybrid approach based on both.

1. Ratan Das Method

This method measures the voltages and the current at a line terminal prior to the fault and during the fault.[12] This method consists of 6 steps for the fault location:

- An estimate of the probable fault location is made from the line parameters and phasors of sequence voltage and currents.
- All laterals in between the fault location and the initial node are ignored and all the load connected to lateral is assumed to be connected to the node where the lateral is connected.
- Load effects (static response type models) are considered by compensation of their currents up to the node just before the faulty node and for a load at remote end.
- All the loads beyond faulty node are considered into a single load at the remote end node and hence the fault sequence voltages and currents are calculated at node F.
- Using the voltage current relationships, the location of the fault is estimated.
If the line has laterals, we may get multiple estimates for the fault and hence we have to convert it to a single estimate. For this purpose, much soft wares are available which convert it down to a single estimate.

2. Mourari Saha Method

“The approach proposed by Saha [13] measures the fundamental frequency voltages and currents measured at a line terminal prior to a fault and during a fault. It implies the estimation of distance to fault on a radial MV system which includes many intermediate load taps by using topology principle.” The calculation of fault location is done by two steps:

- From the calculated data of voltages and currents we measure the fault loop impedance.
- By considering the faults at each successive section, the impedance along the feeder is calculated.

Thereby comparing the measured impedance with the feeder impedance, an estimation of fault location could be obtained, and hence the distance to the fault can be estimated.

The following formula is proposed to estimate a phase-phase fault loop impedance:

\[ Z_K = \frac{V_{pp}}{l_{pp} - (1 - K_{zk})\frac{V_{pp}}{Z_{pre}}} \]  \[\text{5.2.2.1}\]

Where \( V_{pp} \) – “phase to phase fault loop voltage”
\( I_{pp} \) – “phase to phase fault loop current”
\( Z_{pre} \) – “impedance in pre fault conditions”
\( K_{zk} \) – “relation between the power in faulty lines and power in all the lines”

In phase to ground fault, the fault loop impedance is obtained as:

\[ Z_k = \frac{Z_gZ_{pre}}{Z_{pre} - Z_g(1 - K_{zk})(1 - \frac{Z_g}{V_{ph}})} \]  \[\text{5.2.2.2}\]

Where \( Z_g = V_{ph}/(I_{ph} + K_{kn}I_{kn}) \)  \[\text{5.2.2.3}\]

\( V_0 = (V_A + V_B + V_C)/3 \)  \[\text{5.2.2.4}\]

3. The method of superimposed components

To estimate fault in radial distribution lines with several load taps we used the method of superimposed components. For overhead distribution systems [14] this method does
single ended fault location. The difference between pre fault and post fault voltage, i.e. known as superimposed voltage is calculated. We inject this voltage at an assumed fault point to find current in other phases. The injected currents attain a zero value at the actual fault point.

The relation between the voltages at assumed faults to measured voltages and currents is given by:

\[
V_{fa}(\beta) = Z_s Z_m Z_s Z_m I_s V_s a
\]
\[
V_{fb}(\beta) = \beta Z_m Z_s Z_m I_s + V_s b
\]
\[
V_{fc}(\beta) = Z_m Z_m Z_s I_s c V_s c
\]

Where \(\beta\) is the assumed fault location
Zs and Zm are self and mutual line impedance
Vs and Is the measured voltages and current.

The superimposed voltages are thus obtained as

\[
[V'_{fa,b,c}(\beta)] = [V_{fa,b,c} (\beta)] - [V_{fa,b,c (ss)} (\beta)]
\]

And the superimposed currents and voltages at measuring point are given by

\[
[V'_{Sa,b,c}] = [V_{Sa,b,c}]-[V_{Sa,b,c (ss)}]....5.2.3.3
\]
\[
[I'_{Sa,b,c}] = [I_{Sa,b,c}]-[I_{Sa,b,c (ss)}]....5.2.3.4
\]

“For a feeder with multiple taps the computational process is complex however the same principal can be applied.

To represent a load we need to:
- Measure primary impedance of the transformer assuming a power facto between 0.8 to 0.95.
- Type of tap
- Single phase or three phase”

For the first case impedance is given by following equation:

\[
Z_L = \frac{V_l \cdot V_l}{M} \cos^{-1} \varphi ....5.2.3.5
\]

For the second case:

\[
Z_L = 3\frac{V_l \cdot V_l}{M} \cos^{-1} \varphi .....5.2.3.6
\]

Where M is the nominal transformer rating
Vl is the voltage at the load point.

Using the above impedances we can set up a load matrix. “Impedance is supposed to be considered, when a line section is terminated by a primary substation.”

Load level is then calculated to study the variation of the load with time of day to determine the load impedance. Load level is the ratio between the active power fed to feeder at the measuring point and maximum total load.
\[ P_{SS} = \sqrt{3} V_{ls} I_{LS} \cos \varphi \quad \ldots \quad 5.2.3.7 \]
\[ P_{\text{max}} = (M_1 + M_2 + M \ldots + M_n) \cos \varphi \quad \ldots \quad 5.2.3.8 \]

Where \( M \) is the nominal transformer ratio
\( N \) is the number of load taps

Therefore
\[ L_{\text{level}} = \frac{P_{SS}}{P_{\text{max}}} \quad \ldots \quad 5.2.3.9 \]

Hence the impedance of the single phase load tap is given as
\[ Z_L = \frac{V_l \cdot I_l}{L_{\text{level}} M} \sin^{-1} \varphi \quad \ldots \quad 5.2.3.10 \]

Therefore by using this method we get a high accuracy for the majority of systems and fault conditions.

4. The hybrid approach of algorithmic based method and knowledge based

Several other approaches are used in the fault location which implements the use of current/voltage sensors, fault recorders and a good system modal. But this proposal is based on a voltage sag and their currents and hence extracting significant information from them. The information provided is based on the disturbance.

This approach aims at deriving information from the recorded signal of voltage and current during pre-fault conditions and during the fault. Most of the algorithmic methods are based on the stable state information from the fault whereas some other techniques such as neutral nets use vector machines etc to measure the transient information. Therefore as the output of this knowledge based approaches, it describes how to set the algorithmic methods.

“To locate the fault, it is possible to use a well-known algorithmic method using state stable data from the fault registers. Using the result derived from the application of algorithmic method different set of possible fault locations is obtained. At last an intersection of the two possible sets of fault obtained from the two different methods is used to have the most appropriate fault location.”[14]

5.3 Conclusion
Location of fault using the available voltage and current implies saving of great amount of money to the distribution electrical utilities. These results are meaningful in both network planning and network operation. In planning it aims at the design and assessment of sensitive equipment and improving the designs of protection system.
6. Fault Location Matlab Simulation

A transmission line was modeled using Matlab Simulink. The analysis of single line to ground fault location was performed. I used the SimPowerSystem toolbox to perform the simulation.

Table below represents the parameters of line used for the analysis

<table>
<thead>
<tr>
<th>Parameters of Lines</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length</td>
<td>Varying</td>
</tr>
<tr>
<td>Normal Frequency</td>
<td>60 Hz</td>
</tr>
<tr>
<td>Voltage Phase to phase</td>
<td>132 KV</td>
</tr>
<tr>
<td>Resistance Positive sequence</td>
<td>.045531917 ohms/Km</td>
</tr>
<tr>
<td>Resistance Zero Sequence</td>
<td>.0151489359 ohms/Km</td>
</tr>
<tr>
<td>Inductance Positive Sequence</td>
<td>.000617657 Henry/Km</td>
</tr>
<tr>
<td>Inductance Zero Sequence</td>
<td>.001533983 Henry/Km</td>
</tr>
</tbody>
</table>

Table 6.1 Parameters of the line used for analysis

Following diagrams shows the transmission line model. It is modeled using distributed parameter line.

![Diagram](image)

Fig 6.1 Single line diagram for single ended method fault location
6.2 Transmission line Schematic using Matlab/Simulink for single ended method

6.3 Transmission line model with fault location calculation for single ended method
Fig 6.4  Single line diagram for double ended fault location

6.5 Transmission line Schematic using Matlab/Simulink for double ended method

6.6 Transmission line model with fault location calculation for double ended method
All the parameters used are listed in the table 6.1. The length of the transmission line was changed to prove the accuracy of the algorithm. Also model was designed for short transmission line so the effect of its charging current does not need to be considered. During the fault, higher frequency component of frequency are added to the fundamental component of current and voltage waveform. Filtration has been done using low pass band filter.

Fault has been located at the different length of the transmission line. Accuracy of the fault is calculated using following formula.

\[
\text{Percentage Error} = \frac{\text{Calculated Distance} - \text{Actual Distance}}{\text{Length of the line}} \times 100 \quad \text{............6.1}
\]

Table below shows the accuracy of the fault location algorithms for different length and location of the fault.

<table>
<thead>
<tr>
<th>Length of the Line</th>
<th>Distance of the fault</th>
<th>Single ended Fault Location</th>
<th>Double ended fault location</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Matlab Result</td>
<td>%Error</td>
</tr>
<tr>
<td>80</td>
<td>50</td>
<td>52.38</td>
<td>2.975</td>
</tr>
<tr>
<td>100</td>
<td>60</td>
<td>58.568</td>
<td>-1.432</td>
</tr>
<tr>
<td>120</td>
<td>40</td>
<td>37.684</td>
<td>-1.93</td>
</tr>
<tr>
<td>140</td>
<td>80</td>
<td>76.752</td>
<td>-2.32</td>
</tr>
</tbody>
</table>

Table 6.2 Results and % error for Matlab analysis
7. Conclusion

- If power system is homogeneous, and mutual coupling between transmission line is weak, single ended method can be used with large accuracy.

- Traveling wave method is much reliable when time synchronization and other needful equipment is available.

- Double ended fault location algorithm can highly improve the accuracy of fault location. Algorithm used in the project can be used best where fault disturbance recorders or microprocessor relays are available because fault location calculations does not get affected by fault resistance, in-feed effect, different source impedance value.
References


