Location of Unsymmetrical Faults in Power Transmission System Using the Versatile Method of Symmetrical Components

Surendar Kumar Yellagoud1, Sreenivas Reddy Mula2, T. Purnachandra Rao3 and A V R S Sarma4

1Associate Professor, Malla Reddy Engineering college, Dulapally, Secunderabad - 500014, Andhra Pradesh, India
2Assistant Professor, MLR Institute of Technology, Dundigal, Secunderabad, A.P
3Professor(Retd.), National Institute of Technology, Warangal, A.P
4Professor, Osmania University of Engineering, Hyderabad, A.P

Abstract
Calculation of fault location in power transmission system is vital and essential for quick restoration of power to affected consumers. In the transmission system it is very essential to estimate fault location, not only to improve reliability, efficiency and profits of the power system, but also to avoid trials and tribulations involved in exploring faulty domains through manual and other non-automated means and methods. The fundamental features of the calculation of unsymmetrical faults’ location digitally include the sensing of different types of unsymmetrical faults and the utilisation of mathematical expressions for fault location derived using the most versatile method of symmetrical components. The method takes into its fold the four most feasible shunt type of unsymmetrical faults, viz. line-to-line, single-line-to-ground and double-line-to-ground. These mathematical expressions can be conveniently solved using a computer algorithm (digital computer) utilizing the line data available.

Keywords: Fault location, power transmission lines, disturbance recorder, symmetrical components, fault analysis, sequence networks, fault calculation, power reliability.

Introduction
An electrical power system comprises of generation, transmission and distribution of
electric energy. Transmission lines are used to transmit electric power to distant large load centers. The rapid growth of electric power systems over the past few decades has resulted in a large increase of the number of lines in operation and their total length. These lines are exposed to faults as a result of lighting, short circuits, faulty equipments, mis-operation, human errors, overload, and aging. Many electrical faults manifest in mechanical damages, which must be repaired before returning the line to service. In the past, most of the power companies, upon the receipt of fault complaints from the relevant customers/quarters, used to send their inspection crew to patrol the related areas to locate the fault domains using the guidance of system configuration maps and line design manuals. These manual and laborious procedures obviously would tax heavily on inspection costs and drastically delay the restoration time, this in turn had a bad impact on the overall reliability and efficiency of power systems concerned. The restoration can be expedited if the fault location is either known or can be estimated with reasonable accuracy. Faults cause short to long term power outages of customers and may lead to significant losses especially for the manufacturing company/industry. Fast detecting, locating, isolating and repairing of these faults are critical in maintaining a reliable power system operation. When a fault occurs on a transmission line, the voltage at the point of fault suddenly reduces to a low value and result in corresponding changes in current profile of the lines. The importance of this paper arises from the need to reduce the interruptions of electricity, especially for interconnected transmission lines and to reduce the repair and restoration time especially in areas with difficult terrain. The restoration time also includes the time to find the fault location. This can be attained by reducing the error in fault location (distances) estimation. There is no doubt that quick effective repair and maintenance processes directly lead to improve power availability to the consumers which, consequently, enhance the overall efficiency of the power networks. These concepts of availability, efficiency and quality have an increasing importance nowadays due to the new marketing policies resulting from deregulation and liberalization of power and energy markets. Saving time and effort, increasing the power availability can be directly interpreted as a cost reduction or a profit increasing.

The subject of fault location has been of considerable interest to electric power utility engineers for a long time. The development of fault location techniques using digital fault recorded data is essential for power companies to speed the restoration of service and to pinpoint the trouble areas. Digital fault recorders may be available at one terminal of a faulted line. In this case, the apparent impedance concept is a potential candidate to compute the fault location. It should be noted that the apparent impedance concept is based on the sequence networks and the assumption of ideally transposed lines.

In this paper, concept of symmetrical components and the resulting sequence-network equations are used to arrive at appropriate expressions for fault location under different fault conditions. These mathematical expressions can be easily solved using a computer algorithm (digital computer) utilizing the line data available as output from the event analysis software and fault analysis software of disturbance recorder.
**Mathematical Analysis for Unsymmetrical Faults’ Location**

Faults in a power system can be broadly classified into two types, namely, Shunt faults (short circuits) and Series faults (open conductor). Shunt type of faults include conductor to conductor short circuit or conductor(s) to ground short. When circuits are controlled by any protective device(s) which does not open all three phases, one or two phases of the circuit may be opened while the other phases or phase is closed. These faults are called series type of faults. These faults may also occur with one or two broken conductors. Shunt faults are characterised by increase in current and fall in voltage and frequency whereas series faults are characterised by increase in voltage and frequency and fall in current in the faulted phases.

Shunt type of faults are further classified into, Single-Line-to-Ground fault, Line-to-Line fault, Double-Line-to-Ground fault and Three-phase fault. Of these, first three are the unsymmetrical faults as the symmetry is disturbed in one or two phases. The method of symmetrical components is a very useful tool to analyse the unbalanced faults. The 3-phase fault is a balanced fault which can also be analysed using the same tool.

Following are the assumptions for the computation of fault location:

- Transmission lines are assumed to be transposed.
- Resistance of the line and transformer is neglected.
- Charging capacitances of the line is neglected.
- Magnetizing currents of transformers are neglected.
- Mutual Inductances influences on the faulted line are ignored.
- Positive and Negative sequence impedances of the Network are equal.

Modern Power lines are normally not transposed. The transposition however may be affected at the intermediate switching station. It is to be noted that the difference in the inductances of the three phases is negligibly small due to asymmetrical spacing.

Resistance is often omitted, especially in fault calculations done through digital computer programs. Of course, omission of resistance introduces some error, but the results may be satisfactory since the inductive reactance of a system is much larger than its resistance and inductance do not add directly and the impedance is not far different from the inductive reactance if the resistance is small. By simplifying the network equations by omitting line resistance, transformer magnetizing current and the line capacitance the error which is going to come up in the fault calculation will be negligible.

The error in assuming the positive and negative sequence impedances to be equal depends on the location (distance) of the fault with respect to the generator. All the errors are in the assumed generator impedances. Whereas the negative sequence impedance of the generator is constant the positive-phase-sequence reactance will grow larger from sub-transient to synchronous within a very short time after a fault occurs. However, unless the fault is at the terminals of a generator, the constant impedance of transformers and lines between a generator and fault will tend to lessen the effect of changes in the generators’ positive phase-sequence reactance. The assumption that positive and negative phase-sequence impedances are equal is sufficiently accurate for there is negligible overall-error in assuming them to be equal.
**Line –to- Line Fault**

![Line Diagram with Line -to- Line Fault.](image)

**Figure 1:** Line Diagram with Line -to- Line Fault.

Considering a phase-to-phase fault on phases ‘b’ & ‘c’

Where, \( I_a = 0 \), \( I_b = -I_c \), \( V_b - V_c = I_bR_f \) under the above fault condition, symmetrical components for the fault current can be expressed as under.

\[
\begin{bmatrix}
I_{a1} \\
I_{a2} \\
I_{a0}
\end{bmatrix} = \frac{1}{3} \begin{bmatrix}
1 & a & a^2 \\
1 & a^2 & a \\
1 & 1 & 1
\end{bmatrix} \begin{bmatrix}
0 \\
I_b \\
I_c
\end{bmatrix}
\]

\( \therefore I_b = -I_c \)

\( I_{a2} = -I_{a0} \)

\( I_{a0} = 0 \) \hspace{1cm} (1)

Whereas the voltages at fault point, \( F \), is given by,

\[
\begin{bmatrix}
V_{a1} \\
V_{a2} \\
V_{a0}
\end{bmatrix} = \frac{1}{3} \begin{bmatrix}
1 & a & a^2 \\
1 & a^2 & a \\
1 & 1 & 1
\end{bmatrix} \begin{bmatrix}
V_a \\
V_b \\
V_c
\end{bmatrix}
\]

\( \therefore V_c = V_b - R_f I_b \)

From the matrix expression we can write the following equations.

\[
V_{a1} = \frac{1}{3} \left[ V_a + (a + a^2)V_b - a^2R_f I_b \right]
\]

\[
V_{a2} = \frac{1}{3} \left[ V_a + (a + a^2)V_b - aR_f I_b \right]
\]

\[
V_{a0} - V_{a2} = I_{a0}R_f - - - - - - - - - (2)
\]

Equations 1 & 2 suggest a sequence network connection which include a parallel...
combination of positive and negative sequence networks through a series resistance $R_f$ as shown in fig 2.

On inspection of Thevenin’s equivalent of sequence network,

$$E_a = I_{a1}Z_1^1 + I_{a1}R_f - I_{a2}Z_2^1$$

$$\therefore I_{a1} = -I_{a2}$$ and assuming $Z_1^1 = Z_2^1 \& Z_{l_1} = Z_{l_2}$

$$Z_1^1 = K_1Z_{l_1}$$

$$E_a = I_{a1}K_1Z_{l_1} + I_{a1}R_f + I_{a1}K_1Z_{l_1}$$

$$K_1(2Z_{l_1}) = \frac{E_a}{I_{a1}} - R_f$$

$$K_1 = \frac{E_a}{I_{a1}} \left( \frac{1}{2Z_{l_1}} \right) - \frac{R_f}{2Z_{l_1}}$$
Now, referring to Figure 3, which is a simplified circuit with line A-B as faulted line. Here, the remainder circuit of power network w.r.t. faulted line can be simplified into a star combination of impedance elements, $D_1$, $D_2$ and $D_3$ as shown in the figure. Any network irrespective of its complexity can be reduced into a star combination. These impedance elements, $D_1$, $D_2$, $D_3$ are pre-calculated w.r.t. every line, and these are going vary from line to line. These values are supplied by another software module of disturbance recorder. Using $D_1$, $D_2$, $D_3$ w.r.t. faulted line available from D.
R software, and K1, we can calculate apparent fault Impedence (the impedence between D.R and fault point), Zd.

From the simplified circuit (Figure 3.6), we get
Thevenin’s positive sequence Impedence,

\[
Z_1^1 = \frac{(Z_d + D_1)(Z_i - Z_d + D_3)}{Z_i + D_4} + D_3
\]

Also

\[
Z_1^1 = K_1Z_i
\]

Equating both the expressions and cross multiplying will lead to a quadratic equation in variable \(Z_d\):

\[
A Z_d^2 + B Z_d + C = 0
\]

where, \(A = D_4 - Z_{ii}^1\), \(B = D_5 + (Z_{ii}^1 + D_4)*D_3 - D_1 * Z_{ii}^1 + (Z_{ii}^1 + D_4)*K_1 Z_{ii}^1\)
and \(D_4 = D_1 + D_2, D_5 = D_1*D_2\).

By solving quadratic equation, we get \(Z_{d}\).

Fault location in km, \(f_i\):

\[
f_i = \frac{ABS(Z_d)}{Z_{p.u}}
\]

Similarly, fault location expressions can be derived for other type of faults using respective fault conditions and sequence networks.

**Case Study**

Considering a power network [3] consisting of 5 buses, two generators (G1, G2), two transformers(T1, T2) and three transmission lines(TL12, TL13, TL23) as shown in Figure 4 and their respective ratings are tabulated below.

<table>
<thead>
<tr>
<th>Component</th>
<th>MVA Rating</th>
<th>Voltage Rating</th>
<th>(x_1)</th>
<th>(x_2)</th>
<th>(x_0)</th>
</tr>
</thead>
<tbody>
<tr>
<td>G1</td>
<td>100</td>
<td>25KV</td>
<td>0.2</td>
<td>0.2</td>
<td>0.05</td>
</tr>
<tr>
<td>G2</td>
<td>100</td>
<td>13.8KV</td>
<td>0.2</td>
<td>0.2</td>
<td>0.05</td>
</tr>
<tr>
<td>T1</td>
<td>100</td>
<td>25/230KV</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
</tr>
<tr>
<td>T2</td>
<td>100</td>
<td>13.8/230KV</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
</tr>
<tr>
<td>TL12</td>
<td>---</td>
<td>---</td>
<td>0.1</td>
<td>0.1</td>
<td>0.3</td>
</tr>
<tr>
<td>TL13</td>
<td>---</td>
<td>---</td>
<td>0.1</td>
<td>0.1</td>
<td>0.3</td>
</tr>
<tr>
<td>TL23</td>
<td>---</td>
<td>---</td>
<td>0.1</td>
<td>0.1</td>
<td>0.3</td>
</tr>
</tbody>
</table>

**Table 1:** System Data.

Note: Reactances are in p.u
G1, G2 : Generators
T1, T2 : Transformers
1, 2, 3, 4, 5 : Buses
TL12, TL13, TL23 : Transmission Lines

**Table 2:** Summary of Results for all types of faults at a distance of 125km on line 1-3.

<table>
<thead>
<tr>
<th>S. no.</th>
<th>Type of fault</th>
<th>Line</th>
<th>Fault location (in km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Balanced 3-φ fault</td>
<td>1-3</td>
<td>124.9999924</td>
</tr>
<tr>
<td>2</td>
<td>Single line-ground fault</td>
<td>1-3</td>
<td>125.0000229</td>
</tr>
<tr>
<td>3</td>
<td>Phase-to-phase fault</td>
<td>1-3</td>
<td>124.9999771</td>
</tr>
<tr>
<td>4</td>
<td>Double line-ground fault</td>
<td>1-3</td>
<td>125.0000229</td>
</tr>
</tbody>
</table>

**Conclusion and Future Scope**
Using the concepts of symmetrical components the mathematical expressions were derived for fault location, and a computer algorithm can be easily developed to detect different type of faults and calculate fault location.

All the shunt type of faults were simulated at a distance of 125 km from the Disturbance Recorder on the monitored lines. The results are summarized in Table 2. Only shunt type of faults could be detected and evaluated with the algorithm. The algorithm can be further developed to detect and determine the series type of faults, where, one conductor, two and three conductors are open/broken.

**References**

Location of Unsymmetrical Faults
