Combination effects of fault resistance and remote in feed current on simple impedance based fault location

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Abstract: There are many types of fault location algorithms and one of it is simple impedance based fault location algorithm which is still widely used by power system utilities around the world mainly because of no communication channel exists between local and remote substations. The aim of this research is to study the combination effects of remote in feed current and fault resistance on the accuracy of simple impedance based fault location algorithm which is used to estimate fault location when the transmission line is connected to equivalent Thevenin sources from both ends. Simulation has been carried out using Matlab Simulink software for single line-to-ground fault and line-to-line fault. For each type of fault, fault location and fault resistance were varied for two conditions which were when remote breaker in open and remote breaker in close conditions. From the results, it can be concluded that remote in feed current will add additional error to the error due to the existence of fault resistance when fault resistance not equal to zero.

1. Introduction
Fault location is very important in power system. This is because error in fault location estimation given by protection relay or disturbance recorder will make the line to be normalized at a delayed time. It also will make the job to find the fault point becoming more difficult and time consuming. There are many methods used to locate fault location of a line or cable such as using impedance based method [1]–[3], travelling wave method [4]–[6], artificial intelligence or neural network [7]–[9], wavelet transform [10], [11] and several other methods.

Impedance based method uses impedance measurement to calculate the fault location. The calculated impedance represents the distance of fault point from local substation terminal. Impedance based method can be further classified into two categories which are one-terminal algorithms [12]–[14] and two-terminal algorithms [15]–[17]. One-terminal algorithms use measured current and/or voltage signals from local substation only to calculate the loop impedance. It uses many assumptions to calculate fault location. The accuracy of one-terminal algorithm is influenced by many factors such as fault resistance [18], [19], current transformer (CT) measurement error [20], remote infeed current [18], [21], load current [22], [23], shunt capacitance [21] and many other factors. Thus, the accuracy of fault location given by this algorithm is difficult to be confirmed where error can be very substantial.

Many researches have been done using two-terminal algorithms and prove the accuracy of these algorithms. The accuracy of two-terminal algorithms are better than one-terminal algorithms because two-terminal algorithms use measured current and voltage signals from both local and remote substations so that many assumptions in fault location calculation can be avoided [24]. Two-terminal algorithms need communication channel between both local and remote substations. Two-terminal algorithms are becoming as preference by power utilities nowadays to replace existing one-terminal algorithm. However, one-terminal algorithms still widely used in power utilities around the world.
because it will take years to upgrade the standalone line protection relays with two-terminal communication channel and huge amount of cost must be allocated.

This research mainly focuses on studying the combination effects of remote infeed current and fault resistance to simple impedance based fault location algorithm. For each fault type, fault location and resistance were varied with different values. The simulation also was done for two conditions which were during remote breaker in open and remote breaker in close conditions.

2. Related theories

Simple impedance based fault location algorithms

Table 1 shows one-terminal simple impedance based fault location algorithms [25]. The inputs for one-terminal algorithm are phase voltage and current signals from local substation only. For single line-to-ground (SLG) fault, ground compensation factor, ‘k’ must be included in the algorithm to compensate for ground effect in zero sequence loop impedance calculation. Using the algorithms, impedance seen by protection relays or fault locators can be calculated. To get fault location in kilometer (km), the calculated impedance must be divided with total line impedance and multiplied with total line length.

| Fault Types | Fault Location Algorithms |
|-------------|---------------------------|
| AG          | $V_a / (I_a + k*3*I_0)$   |
| BG          | $V_b / (I_b + k*3*I_0)$   |
| CG          | $V_c / (I_c + k*3*I_0)$   |
| AB or ABG   | $V_{ab} / I_{ab}$         |
| BC or BCG   | $V_{bc} / I_{bc}$         |
| CA or CAG   | $V_{ca} / I_{ca}$         |

Where:

- $k = (Z_{0L} - Z_{1L}) / 3Z_{1L}$
- $Z_{0L}$ = zero sequence line impedance
- $Z_{1L}$ = positive sequence line impedance
- $I_0$ = zero sequence current

Remote infeed current

One-line diagram for a transmission line with a fault is shown in figure 1. When a fault occurs at ‘m’ location from local substation terminal, current from local substation, $I_S$ and remote substation, $I_R$ will both flow through fault resistance, $R_f$. So, fault current is the combination of local and remote substation currents. The value of current from local and remote substations depends on the equivalent Thevenin short circuit level of each substation. Fault resistance can be due to the existence of fault arc or a body directly touching the phase line. Both currents will flow to fault point and return back to the substation terminals. In one-terminal fault location algorithm, the equation does not include remote substation current (or remote infeed current) where it only considers local measured current. This will make the calculated fault location given by local substation is not confirmed which can be substantial and add additional error to the error caused by the existence of fault resistance.

![Figure 1](image_url)

**Figure 1.** One-line diagram of a line fault
3. Methodologies

The method started with modelling the transmission line and equivalent local and remote sources’ subsystems. Table 2 shows the parameters used in the simulation model. The line is classified as a short single circuit transmission line. Both ends of the line are connected to the substations which are represented by three-phase Thevenin equivalent sources. To see the combination effects of remote infeed current and fault resistance on the performance of fault location estimation during fault occurrence, comparison was made between fault location estimations during open and close conditions of remote end breaker. The error percentages for both conditions were compared and analyzed. Fault resistance also was changed from solid fault to fault with 2 Ω and 5 Ω resistance values and the effects were analyzed for both remote end breaker conditions.

Table 2. Parameters for simulation model

| Parameters                        | Value          | Unit               |
|-----------------------------------|----------------|--------------------|
| Local and Remote Substations      |                |                    |
| Three-phase Voltage              | 132 x 10³      | Volt (V)           |
| Nominal Frequency                 | 50             | Hertz (Hz)         |
| Phase Angle of Phase A            | 0              | Degree (°)         |
| Short Circuit Level               | 1.044 x 10⁹    | Volt Ampere (VA)   |
| X/R Ratio                         | 0              | -                  |
| Transmission Line                 |                |                    |
| Positive Sequence Resistance, R₁ | 4.553 x 10⁻²   | Ω/km               |
| Zero Sequence Resistance, R₀      | 0.1515         | Ω/km               |
| Positive Sequence Inductance, L₁ | 6.1765 x 10⁻⁴ | H/km               |
| Zero Sequence Inductance, L₀      | 1.534 x 10⁻³   | H/km               |
| Line Length, L                    | 47             | Km                 |

Figure 2 shows the overall simulation model of the developed system. Breaker at the left side of the model is to initiate fault at a set time. Fault resistance, R_f value also was set using the breaker internally. Transmission line, measurement and equivalent substation sources are inside transmission line subsystem. For SLG fault, port A of the transmission line subsystem was connected to the ground while for line-to-line (LL) fault, port A was connected to port B. Voltage and current signals are filtered using low pass filter block to filter all harmonic components except fundamental component during fault occurrence. The function of Fourier transform subsystem is to get the magnitudes and angles of the fundamental voltage and current signals. There are two fault location algorithm subsystems located at the right side of the model to calculate fault locations in kilometer (km) for LL and SLG faults. Both subsystems were created using trigonometric expansion for the algorithms stated in Table 1.

Figure 2. Overall simulation model

The blocks inside the transmission line subsystem are shown in figure 3. Local substation and remote substation blocks represent the three-phase Thevenin equivalent sources for local and remote substations respectively. The transmission line is divided into two parts to represent the fault point at any location between local and remote substations. The function of remote end breaker is to open and
close the line at remote end.

Figure 3. Blocks inside transmission line subsystem

4. Results and discussion

Two types of fault were simulated using Matlab Simulink. The fault types are SLG and LL faults. For each type of fault, remote breaker located at the end of the line connected to remote substation was opened and closed separately. For each open and close condition, fault point was varied from point near local substation until point near remote substation. Actual fault location also was varied for three different fault resistance, $R_f$ values which are solid fault ($R_f = 0 \, \Omega$), $R_f = 2 \, \Omega$ and $R_f = 5 \, \Omega$. Fault location errors between estimated fault locations and actual fault locations for each fault type with different fault points and fault resistances were calculated, put in tables and plotted onto graphs.

**SLG fault**

$R_f = 0 \, \Omega$

Table 3 shows the fault location errors for SLG fault with $R_f = 0 \, \Omega$ while figure 4 shows the graph of the plotted errors. From both table and figure, it can be seen that the errors are very small where the highest error is -2.745% for fault at 40 km from local substation when remote breaker in close condition. No significance difference can be seen between the errors for remote breaker in open condition with the errors for remote breaker in close condition.

| Actual Fault Location (km) | Remote Breaker in Close Position | Remote Breaker in Open Position |
|---------------------------|---------------------------------|---------------------------------|
|                           | Estimated Fault Location (km)   | Error (%)                       | Estimated Fault Location (km) | Error (%) |
| 5                         | 5.143                           | 0.304                           | 4.957                         | -0.091    |
| 10                        | 10.07                           | 0.149                           | 9.959                         | -0.087    |
| 15                        | 15.17                           | 0.362                           | 14.96                         | -0.085    |
| 20                        | 20.07                           | 0.149                           | 19.94                         | -0.128    |
| 25                        | 24.9                            | -0.213                          | 24.95                         | -0.106    |
| 30                        | 29.65                           | -0.745                          | 29.98                         | -0.043    |
| 35                        | 34.26                           | -1.574                          | 34.95                         | -0.106    |
| 40                        | 38.71                           | -2.745                          | 39.96                         | -0.085    |

Figure 4. Plot of fault location errors for SLG fault with $R_f = 0 \, \Omega$

$R_f = 2 \, \Omega$

Table 4 shows the fault location errors for SLG fault with $R_f = 2 \, \Omega$ while figure 5 shows the graph of the plotted errors. From both table and figure, it can be seen that the errors of fault location for both
remote breaker in open and in close conditions increase significantly compared to the errors for solid fault ($R_f = 0 \, \Omega$). However, the errors of fault location for remote breaker in close condition are significantly higher than the errors for remote breaker in open condition.

| Actual Fault Location (km) | Remote Breaker in Close Position | Remote Breaker in Open Position |
|----------------------------|----------------------------------|--------------------------------|
|                            | Estimated Fault Location (km)    | Error (%)                      |
|                            | Estimated Fault Location (km)    | Error (%)                      |
| 5                          | 13.62                            | 18.340                         |
| 10                         | 17.25                            | 15.426                         |
| 15                         | 21.7                             | 14.255                         |
| 20                         | 26.47                            | 13.766                         |
| 25                         | 31.39                            | 13.596                         |
| 30                         | 36.36                            | 13.532                         |
| 35                         | 41.37                            | 13.553                         |
| 40                         | 46.35                            | 13.511                         |

When remote breaker in open condition, the increase of errors was because of contribution from fault resistance which was not equal to zero. But, when remote breaker in close condition, remote infeed current contributed additional error in fault location estimation. Combination of fault resistance which was not equal to zero with remote in feed current during remote breaker in close condition has made fault location errors become very high. When fault resistance exists during fault, remote infeed current will flow into it and the actual current flow through fault resistance is the combination of local current and infeed current but the remote infeed current is not seen by local fault location algorithm thus it contributes additional error in simple impedance based fault location algorithm which only consider local measured current.

$R_f = 5 \, \Omega$

Fault location errors for SLG fault with $R_f = 5 \, \Omega$ is shown in table 5 while figure 6 shows the graph of the plotted errors. It can clearly be seen that the errors are more severe than the errors for $R_f = 2 \, \Omega$ for both remote breaker in open and in close conditions.

| Actual Fault Location (km) | Remote Breaker in Close Position | Remote Breaker in Open Position |
|----------------------------|----------------------------------|--------------------------------|
|                            | Estimated Fault Location (km)    | Error (%)                      |
|                            | Estimated Fault Location (km)    | Error (%)                      |
| 5                          | 29.96                            | 53.106                         |
| 10                         | 33.34                            | 49.660                         |
| 15                         | 37.56                            | 48.000                         |
| 20                         | 42.11                            | 47.043                         |
| 25                         | 47.06                            | 46.936                         |
| 30                         | 52.32                            | 47.489                         |
| 35                         | 57.85                            | 48.617                         |
| 40                         | 63.5                             | 50.000                         |
| 5                          | 29.96                            | 53.106                         |
| 10                         | 33.34                            | 49.660                         |
| 15                         | 37.56                            | 48.000                         |
| 20                         | 42.11                            | 47.043                         |
| 25                         | 47.06                            | 46.936                         |
| 30                         | 52.32                            | 47.489                         |
| 35                         | 57.85                            | 48.617                         |
| 40                         | 63.5                             | 50.000                         |
Figure 6. Plot of fault location errors for SLG fault with $R_f = 5 \, \Omega$

**LL fault**

$R_f = 0 \, \Omega$

Table 6 shows the fault location errors for LL fault with $R_f = 0 \, \Omega$ while figure 7 shows the graph of the plotted errors. From both table and figure, it can be seen that the errors are very small with the highest error is $1.298\%$ for fault at 20 km from local substation when remote breaker in open condition.

| Actual Fault Location (km) | Remote Breaker in Close Position | Remote Breaker in Open Position |
|----------------------------|---------------------------------|---------------------------------|
|                            | Estimated Fault Location (km)  | Error (%)                       | Estimated Fault Location (km)  | Error (%)                       |
| 5                          | 4.927                           | -0.155                          | 4.748                           | -0.536                          |
| 10                         | 9.786                           | -0.455                          | 10.4                             | 0.851                           |
| 15                         | 14.6                            | -0.851                          | 15.23                            | 0.489                           |
| 20                         | 20.1                            | 0.213                           | 20.61                            | 1.298                           |
| 25                         | 24.93                           | -0.149                          | 25.44                            | 0.936                           |
| 30                         | 29.93                           | -0.149                          | 30.1                             | 0.213                           |
| 35                         | 34.99                           | -0.021                          | 35.07                            | 0.149                           |
| 40                         | 39.98                           | -0.043                          | 39.83                            | -0.362                          |

From the graph, there is no big difference between the errors for remote breaker in close condition with the errors for remote breaker in open condition. This is because when the fault is a solid fault, fault point is just like a node where local and remote currents will flow into it and return back to substations without flowing through any fault resistance. Thus, for solid fault, remote in feed current will not give any influence on fault location algorithm at local substation for any type of fault.
$R_f = 2 \ \Omega$

Fault location errors for LL fault with $R_f = 2 \ \Omega$ is shown in table 7 while figure 8 shows the graph of the plotted errors. From both table and figure, it can be seen that the errors of fault location for both remote breaker in open and in close conditions increase significantly compared to the errors for solid fault ($R_f = 0 \ \Omega$). However, the errors of fault location during remote breaker in close position are significantly higher than the errors during remote breaker in open condition. The reason for this significance errors is similar with the explanation for SLG fault with fault resistance not equal to zero.

| Actual Fault Location (km) | Remote Breaker in Close Position | Remote Breaker in Open Position |
|---------------------------|---------------------------------|---------------------------------|
|                           | Estimated Fault Location (km)   | Error (%)                       | Estimated Fault Location (km)   | Error (%)                       |
| 5                         | 11.36                           | 13.532                          | 7.52                            | 5.362                           |
| 10                        | 14.7                            | 10.000                          | 12.13                           | 4.532                           |
| 15                        | 19.34                           | 9.234                           | 17.64                           | 5.617                           |
| 20                        | 24.07                           | 8.660                           | 21.35                           | 2.872                           |
| 25                        | 29.08                           | 8.681                           | 27.7                            | 5.745                           |
| 30                        | 34.15                           | 8.830                           | 31.39                           | 2.957                           |
| 35                        | 39.17                           | 8.872                           | 36.38                           | 2.936                           |
| 40                        | 44.48                           | 9.532                           | 41.15                           | 2.447                           |

**Figure 8.** Plot of fault location errors for LL fault with $R_f = 2 \ \Omega$

$R_f = 5 \ \Omega$

Table 8 shows the fault locations errors for LL fault with $R_f = 5 \ \Omega$ while figure 9 shows the graph of the plotted errors. It can clearly be seen that the errors are more severe than errors for $R_f = 2 \ \Omega$ for both remote breaker in open and in close conditions.

| Actual Fault Location (km) | Remote Breaker in Close Position | Remote Breaker in Open Position |
|---------------------------|---------------------------------|---------------------------------|
|                           | Estimated Fault Location (km)   | Error (%)                       | Estimated Fault Location (km)   | Error (%)                       |
| 5                         | 22.51                           | 37.255                          | 13.56                           | 18.213                          |
| 10                        | 26.62                           | 35.362                          | 17.22                           | 15.362                          |
| 15                        | 30.36                           | 32.681                          | 21.16                           | 13.106                          |
| 20                        | 34.9                            | 31.702                          | 25.4                            | 11.489                          |
| 25                        | 39.47                           | 30.787                          | 30.42                           | 11.532                          |
| 30                        | 44.23                           | 30.277                          | 35.05                           | 10.745                          |
| 35                        | 49.69                           | 31.255                          | 39.78                           | 10.170                          |
| 40                        | 54.55                           | 30.957                          | 44.56                           | 9.702                           |
5. Conclusion
Simulation has been successfully carried out to study the combination effects of remote infeed current and fault resistance on local simple impedance based fault location algorithm. It can be said that remote infeed current will add additional error to the fault location algorithm at local substation when fault resistance is not equal to zero where the error can be very substantial when the fault resistance is high. However, when fault resistance equal to zero, remote infeed current will not give any effect to fault location algorithm at local substation because the fault location is just like a point where local and infeed currents will flow to it and return back to the substations. Besides that, fault location error will increase significantly with the increase of fault resistance for both remote breaker in open and remote breaker in close conditions. The effects have been studied for two types of fault which are SLG and LL faults.

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