Modeling and Computer Simulation of Fault Calculations for Transmission Lines

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Abstract- Calculation of transmission line faults has a fundamental importance in the fault detection, classification, and location determination of faults in transmission line. This paper presents a proposed computer program based on Matlab software to calculate all ten types of shunt faults that may occur in a transmission line. Various fault scenarios (fault types, fault locations and fault impedance) are considered in this paper. The inputs of the proposed program are line length, source voltage, positive, negative and zero sequence for source impedance, line charging, and transmission line impedance. The output of the algorithm is used to train an artificial intelligence networks to detect, classify and locate transmission lines faults. Simulation results have shown the effectiveness of the algorithm under the condition of all types of shunt faults.

Keywords- Fault Calculation, Single line to ground fault, Double line to ground fault, Double line fault, three-phase fault.

I. INTRODUCTION

Transmission line is a very delicate part of the electrical network because it is an out-door equipment which can run to several hundreds of kilometers and is subjected to different types of faults [1]. The transmission line is exposed to different types of faults such as single line to ground fault, SLG, double line to ground fault, DLG, double line fault, DL, three-phase fault [2]. Modeling and simulation of Fault calculation is the analysis of transmission line behavior under different fault conditions, with particular reference to the effects of these conditions on the transmission line current and voltage values. Together with other aspects of system analysis, fault calculation forms an indispensable part of the whole function and process of transmission line design. Before selecting proper protective devices, it is necessary to determine the likely fault currents that may result in a system under various fault conditions [3].

Correct design depends essentially on a full knowledge and understanding of system behaviour and on the ability to predict this behaviour for the complete range of possible system conditions. Accurate and comprehensive analysis, and the means and methods of achieving it, are therefore of essential importance in obtaining satisfactory transmission line performance and in ensuring the continued improvement in performance which results from the development and application of new methods and techniques. Depending upon the complexity of the system the calculations could also be too much involved [2]. Accurate fault current calculations are normally carried out using an analysis method called symmetrical components [3,4]. This method is used by design engineers and practicing protection engineers, as it involves the use of higher mathematics. It is based on the principle that any unbalanced set of vectors can be represented by a set of three balanced quantities, namely: positive, negative and zero sequence vectors. Therefore, calculation of faults in transmission lines is an important issue in designing of protective devices. Due to limited available amount of practical fault data, it is necessary to generate examples of fault data using simulation. To generate data for the typical transmission system, this paper used to generate the fault current and voltage for different faults scenario. The simulation of different fault types (a-g, b-g, c-g, a-b, b-c, c-a, ab-g, bc-g, ca-g, and abc-g) and conditions (inception angles, 0, 0\(^\circ\), 90\(^\circ\), and fault resistances 0Ω, 200Ω) were conducted at various locations on the transmission lines. The output of this paper is used to generate simulation data for the typical any transmission line in normal and faulty conditions to detect, classified and located and cleared as fast as possible.

To validate the proposed approach, extensive simulation studies have been carried out using computer program based on MATLAB for different types of fault considering wide variations in fault location, fault inception angle and fault impedance.

II. METHODOLOGY

The analysis of fault currents will give information about the nature of the faults. Let us consider a faulted transmission line extending between two power systems as shown in Fig. 1 is considered in this study. The faulted transmission line is represented by distributed parameters. Let us consider the point (F) of fault may be located at any distance of the faulted line can be assigned a new bus number and the faulted transmission line is broken into three sequence networks, namely positive, negative and zero sequence network. In order to calculate fault current and voltage of faulted transmission line, the bus impedance matrix at point (F) for each sequence network is obtained separately, then the sequence impedances, \( Z_1 \), \( Z_2 \) and \( Z_3 \) are connected together according to fault type. The fault formula for balanced and various unbalanced faults are summarized below:

II-1 Modeling of SLG Faults Using \( Z_{bus} \)

The SLG fault, the most common type, is caused by lighting or by conductors making with ground structures.

Consider a fault between phase (a) and ground as shown in Fig. 2 through impedance \( Z_i \) at bus 3, point (F). The transmission line is broken into three sequence networks, namely positive, negative and zero sequence network [5,6].
The conditions at the fault bus 3 (point F) are expressed by the following equations:-

\[ I_{fa}=0, I_{lc}=0 \] \hspace{1cm} (1)

The following equations give relationships between sequence components of fault currents at the fault point.

\[ I_{fa}^0 = I_{fa}^1 = I_{fa}^2 = \frac{V_{f}^{pre}}{Z_{33}+Z_{33}+Z_{f}} \] \hspace{1cm} (2)

Where \( Z_{33}^0 \), \( Z_{33}^1 \) and \( Z_{33}^2 \) are the diagonal elements of the corresponding bus impedance matrix. The fault line current at bus 3 can be calculated as follows [2,3,4,5]:

\[ I_{fa} = I_{fa}^0 + I_{fa}^1 + I_{fa}^2 \] \hspace{1cm} (3)
\[ I_{fb} = I_{fb}^0 + a^2, I_{fb}^1 + a, I_{fb}^2 \] \hspace{1cm} (4)
\[ I_{fc} = I_{fc}^0 + a, I_{fc}^1 + a^2, I_{fc}^2 \] \hspace{1cm} (5)

We rewrite the above equation in matrix notation as

\[ I_{abc} = T I_{fa} \] \hspace{1cm} (6)

Where \( T \) is known as symmetrical components transformation matrix which transforms phasor currents \( I_{abc} \) into component currents \( I_{012} \), and is

\[ T = \begin{bmatrix} 1 & 1 & 1 \\ 1 & -0.5 - j0.866 & -0.5 + j0.866 \\ 1 & -0.5 + j0.866 & -0.5 - j0.866 \end{bmatrix} \] \hspace{1cm} (7)

\( V_{f}^{pre} \): The prefault voltage at point F (bus 3) and can be calculated by using two port network as shown in Fig. 3.

\[ V_{f}^{pre} = D_{1}V_{fa}^{pre} - B_{1}I_{fa}^{pre} \] \hspace{1cm} (8)

Where:

The \( A_{1}, B_{1}, C_{1}, D_{1} \) parameters can be calculated, as [9]

\[ A_{1} = D_{1} = \cosh(\gamma L_{f}) \] \hspace{1cm} (9)
\[ B_{1} = Z_{s} \sinh(\gamma L_{f}) \] \hspace{1cm} (10)
\[ C_{1} = 1/Z_{s} \sinh(\gamma L_{f}) \] \hspace{1cm} (11)

By defining the propagation constant per unit length for symmetrical transmission line with distributed parameters:-

\[ \gamma = \sqrt{(R + j0. L), (G + j0. C)} \] \hspace{1cm} (12)

and the characteristic impedance of the line

\[ Z_{c} = \sqrt{(R + j0. L)/(G + j0. C)} \] \hspace{1cm} (13)

**II-II Modeling of DL Faults Using \( Z_{bus} \):**

Consider a fault between phase b and c through an impedance \( Z_{f} \) at point F as shown in Fig. 4. The following relations must be satisfied at the fault point

\[ I_{fa}=0, I_{fb}=-I_{fc} \] \hspace{1cm} (14)

The symmetrical components of fault current is

\[ I_{fa}^0 = 0 \] \hspace{1cm} (15)
\[ I_{fa}^1 = -I_{fa}^2 = \frac{V_{f}^{pre}}{Z_{33}+Z_{33}+Z_{f}} \] \hspace{1cm} (16)

The fault line currents can be obtained from Equation (6).

**II-III Modeling of DLG Faults Using \( Z_{bus} \):**

Consider a fault between phase b and c through an impedance \( Z_{f} \) to ground at point F (bus 3) as shown in Fig. 5. The fault is taken to be on phase’s b and c, and the relations now existing at the fault bus 3 are

\[ I_{fa}=0 \] \hspace{1cm} (17)
The symmetrical components of fault current is

\[ I_{fa}^1 = \frac{V_{fa}^0}{Z_{L}^1 + Z_{L}} \]

\[ I_{fa}^2 = \frac{-V_{fa}^0}{Z_{L}^1 + Z_{L}} \]

\[ I_{fa}^0 = \frac{-V_{fa}^0}{Z_{L}^1 + Z_{L}} \]

The fault line currents can be obtained from Equation (6)

II-IV Modeling of three-phase Faults Using \( Z_{bus} \)

Assuming the three-phase system fault as shown on Fig. 6 occurs at bus 3 on phases a, b and c, all through the same fault impedance \( Z_{f} \)

The symmetrical components of fault current are given by the following Equation:

\[ I_{fa}^1 = 0 \]

\[ I_{fa}^2 = \frac{V_{fa}^0}{Z_{L}} \]

\[ I_{fa}^0 = 0 \]

The fault line currents can be obtained from Equation (6)

II-V Modeling of Sending Voltage and Line current during Fault [5]

Using sequence components of the fault currents the symmetrical components of the sending end bus voltage during fault can be obtained by the following Equations:

\[ V_{sa}^0 = 0 - Z_{L}^1 I_{fa}^2 \]

Where;

\[ Z_{L}^1 = L_{s} \]

\[ Z_{L}^0 = L_{s} Z^1 \]

\[ Z_{L}^2 = (L - L_s)Z^2 \]

\[ Z_{L}^3 = (L - L_s)Z^2 \]

Where \( Z^1 \), \( Z^2 \) and \( Z^0 \) : The matrix impedance of transmission line per unit length.

\[ V_{sa}^0(0) \] : The prefault phase voltage at sending end. The phase voltages at sending end during fault are

\[ V_{sa}^{abc} = T_{abc} V_{sa}^{012} \]

The symmetrical components of fault current in line 1 to 3 is given by

\[ I_{fa}^1 = \frac{V_{fa}^0 - V_{fa}^0}{Z_{L}^1 + Z_{L}} \]

\[ I_{fa}^2 = \frac{V_{fa}^0 - V_{fa}^0}{Z_{L}^1 + Z_{L}} \]

\[ I_{fa}^0 = \frac{V_{fa}^0 - V_{fa}^0}{Z_{L}^1 + Z_{L}} \]

The line fault currents from Bus 1 to Bus 3 (point F) can be obtained as follows:-

\[ I_{abc} = T_{abc} I_{abc}^{012} \]

III. COMPUTER SIMULATION OF FAULT CALCULATION

The flow chart of the proposed computer program is shown in Fig. 7. The proposed computer program simulates various faults for different fault conditions, i.e. a-g, b-g, c-g, ab, bc, ca, ab-g, bc-g, ca-g, and abc fault) based on \( Z_{bus} \). The condition parameters that have been taken into account for each fault type are:

1) Variation of fault impedance, \([0: 200] \) (\( \Omega \)).
2) Variation of fault angle, \([0: 90] \) (degree).
3) Variation fault locator \([1: 200] \) km.

![Figure 6. A balanced three-phase fault at point F](image)

![Figure 7. Flowchart of the proposed computer program](image)
IV. APPLICATION AND RESULTS

Several fault conditions have been studied in the evaluation of the algorithm efficiency, analyzing the fault distance and impedance, fault inception angle as well as the fault type. To evaluate the performance of the proposed algorithm, let us consider a faulted transmission line extending between two sources as shown in Fig. 1. The faulted transmission line is represented by distributed parameters. As an application, a 200 km overhead transmission line with the parameters of the transmission line model of Fig. 1 is as follows

- **Source voltages:**
  - Source S: $V_1 = 400$ kV; source R: $V_2 = 400$ kV.
- **Source impedance (both sources):**
  - Positive sequence impedance = $1.31 + j15.0$;
  - Zero sequence impedance = $2.33 + j26.6$;
- **Frequency = 50 Hz;**
- **Transmission line impedance:**
  - Positive sequence impedance = $8.25 + j94.5$;
  - Zero sequence impedance = $82.5 + j308$;
  - Positive sequence capacitance = $13$ nF/km;
  - Zero sequence capacitance = $8.5$ nF/km.

The significant parameters above are selected based on real operations [8].

A. Influence of the Fault Distance and Fault Impedance

For an analysis of the influence of the variation of the fault distance and fault impedance in the performance of the proposed algorithm, considering cases single line to ground faults, double line to ground faults, double line faults and three-phase faults, all with 10° fault inception angle were simulated. The results presented in Fig. 8-11. The voltage at sending end at each case is shown in Fig. 12-15. It can be verified from results presented in Figs. 8-15, that the method is sensitive to the variation of fault distance and fault impedance.
B. Influence of the inception angle and Fault Impedance

The fault impedance and fault inception angle influence on the algorithm accuracy was also analyzed, considering cases single line to ground faults, double line, double line to ground faults and three-phase faults, all with 5 km line length from local terminal. The results presented in Fig. 16-19. As it can be observed from Figs. 20-23, the fault current slightly affect the fault current at sending end.
C. Influence of the inception angle and Fault Distance

The fault distance and fault inception angle influence on the algorithm accuracy was also analyzed, considering cases single line to ground faults, double line, double line to ground faults and three-phase faults, all with 30 ohm fault impedance. The results presented in Fig 24-30.
This paper presents a computer package to perform short, medium or long transmission line fault analysis based on Z_{bus} methods along with the symmetrical components method. From the results obtained, the salient conclusions of this paper are:

1- Calculates the fault conditions and to provide protective equipment designed to isolate the faulted zone from the reminder of the system in the appropriate time.

2- Presents a highly accurate transmission line simulation technique which is utilized to calculate voltages and currents at the relay location (Sending end S) for different fault types, fault conditions and different power system data.

3- Calculate faults along different line lengths.

The results show that the method is suitable for design a protective scheme for transmission line based on artificial intelligence. As the method is easy applicable and it is flexible, it can be used for modeling any other transmission lines.

REFERENCES


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