Fuzzy Logic Based Fault Detection and Classification of Unsynchronized Faults in Three Phase Double Circuit Transmission Lines

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Abstract: A vital attribute of electrical power network is the continuity of service with a high level of reliability. This motivated many researchers to investigate power systems in an effort to improve reliability by focusing on fault detection, classification and localization. In this paper a new approach to fault location for double-circuit transmission lines based on only the voltage data of both ends of the faulted circuit is described. The ratio between the magnitudes of negative-sequence voltages measured at both ends of the faulted circuit is utilized to estimate the fault location and a fuzzy logic based algorithm to classify the unsynchronized faults for three phase double circuit transmission lines has been developed. To demonstrate the effectiveness of this method, simulations considering various operating conditions have been performed on MATLAB. The results show that proposed technique is capable of right tripping action and classification of type of fault therefore can be employed in practical applications.

Keywords: Double Circuit Transmission Lines, Fault Classification, Negative Sequence, Voltage Magnitudes, and Fuzzy Logic.

I. INTRODUCTION

Modern power system is a complex network and requires high-speed, precise, and reliable protective system. Faults in power system are unavoidable and overhead transmission line faults are generally higher compare to other major components. Due to recent technology advances, new and improved devices for protection of power system are being designed and developed. Fault classification and location in double circuit line with conventional techniques is difficult due to mutual coupling between the two circuits. This mutual coupling is compensated by taking zero sequence current into account. The goal of system protection includes detection, classification and location of fault with minimum time delay.

Whether they are for single-circuit or double-circuit transmission lines, there are two types of fault-location methods known as one-end-based and two-end-based ones. The one-end-based methods may suffer from errors due to the variations of source impedance, fault incidence angle, and loading conditions while their major merit is that they need data of only one end. To overcome the shortfalls of one-end-based methods, two-end-based methods were introduced.

They can be classified into unsynchronized and synchronized ones. Unsynchronized methods do not need the data of both line ends to be synchronized while data synchronization is the first step in the synchronized methods. Power grids around the globe are undergoing massive transformation towards smart power grids with the help of rapidly developing monitoring and control methodology. Among them detecting the fault and the phase which underwent the fault is of great importance. Classification of fault has the area of interest for numerous researchers and as an outcome several fault classification methods have been implemented over the time. Some of the prominent methods are: Neural network based technique, wavelet transforms based technique, fuzzy and fuzzy-network based technique, etc. Thomas Dalstein and Beind Kulicke have proposed a method using digital signal processing implementation and neural network architecture concept for fault classification1. Huisheng Wang et al. presented a novel method to real-time classification of faults in transmission lines with the help of neuro-fuzzy methods2. A travelling waves and fuzzy logic technique has been presented by Parmod Kumar et al., in 3. Kaveh Razi et al. presented an approach to classify faults using fuzzy logic approach and full cycle discrete Fourier transform4. The wavelet technique uses the method of oscillography5.

The information of faults and power quality disturbances are recorded in the form of oscillographic data. This kind of computation is quiet complex and uses a lot of processing power. Up till now, several methods have been proposed for fault location on double-circuit transmission lines, Chen et al. [6] presented a fault-location method based on the distributed line model. This method requires the phasor measurement units (PMUs) for synchronized data and continuous monitoring of the line under normal operation. Funabashi et al. [7] presented two algorithms for multi terminal double-circuit transmission lines based on “impedance calculation” and “current diversion ratio.” The synchronization for voltages and currents at all terminals is required. Kang et al. [8] developed a fault-location algorithm for untransposed double-circuit transmission lines based on the lumped parameter model of transmission lines by ignoring the line shunt capacitances. This may cause significant errors in long
transmission lines. Besides, fault classification is required for fault location. Than the practical one that is around 1 kHz [9]. Assuming both relays are provided with the source impedance behind them, which are available at load dispatch centres [10], in this paper fuzzy logic based fault detection and classification on real time has been proposed.

Post-fault three phase currents; zero sequence and positive sequence current Samples are taken into account for fault classification. In this paper fuzzy logic based fault detection and classification on real time has been proposed. Post-fault three phase currents; zero sequence and positive sequence current samples are taken into account for fault classification. Assuming both relays are provided with the source impedance behind them, which are available at load dispatch centres, this paper presents a new fault-location method for double-circuit transmission lines using the magnitudes of negative-sequence voltages measured at both ends of the faulted circuit. The rest of this paper is organized as follows. Section II presents a detailed description of the proposed method, and Section III gives a detailed study about fault classification and implementation of fuzzy logic approach Section IV is devoted to accuracy evaluation of the proposed method to the parameters which are required for fault location. Section V presents the numerical simulation to demonstrate the proposed method. The simulation results were obtained by using the steady-state data of post fault analysis carried out in MATLAB/SIMULINK. Finally, conclusions are drawn in Section VI.

II. PROPOSED METHOD

The method adopted for the study is applied on single line diagram shown in Fig. 1 which is protected by distance relays Rs and Rr. It is observed during the analysis of the data that depending on the type of fault i.e. line to ground faults, line to line faults, line to line to ground faults or three phases fault, the waveform changes accordingly. It is significant to mention that during fault the voltage tends to reduce to zero and current tends to rise.

If an unbalanced fault occurs at distance \( m \) [per unit (p.u.)] from relay in one circuit of the line, the negative-sequence circuit can thus be modeled as shown in Fig. 2.

\[
V_{2F} = V'_{2F} \frac{X_{2S}}{mX_{2L} + X_{2S}}
+ X_{2NY} \cdot V'_{2F} \frac{1}{mX_{2L} + X_{2S}}
+ \frac{1}{(1 - m)X_{2L} + X_{2R}}
\]

Fig 1. Double-circuit transmission line protected by the distance relays of sending and receiving ends Rs, and Rr.

\[
V_{2L} = V_{2L} \left( \frac{X_{2R}}{(1 - m)X_{2L} + X_{2R}} \right)
\]

Post-fault three phase currents; zero sequence and positive sequence current Samples are taken into account for fault classification. In this paper fuzzy logic based fault detection and classification on real time has been proposed.

Fig 2. Negative-sequence circuit of the double-circuit transmission line after converting the delta connection to the Y connection.

Where \( V_{2F} \) is the voltage between the fault point and the star point of the Y connection in the negative-sequence circuit. Considering only the phasor magnitudes and dividing above equations yields \( k \) value Where,

\[
k = \frac{X_{2S}}{V_{2R}}
\]

\[
\frac{X_{2S}^2}{V_{2R}} + X_{2NY} \left( \frac{1}{mX_{2L} + X_{2S}} + \frac{1}{(1 - m)X_{2L} + X_{2R}} \right)
\]

Solving in terms of \( m \) leads to

\[
m = \frac{2(1 - k)X_{2S}X_{2R} + X_{2S}X_{2L}}{X_{2L}(X_{2S} + kX_{2R})}
\]

As a result, knowing (the ratio between the magnitudes of negative-sequence voltages at the sending, S, and receiving, R, ends of the faulted circuit) and the negative-sequence reactances of the sources and that of the line, the fault location in a double circuit transmission line can be estimated by using \( m \). Here, it can be argued that the same results can also be obtained by using the zero-sequence circuit. The following outlines the reasons why the negative-sequence circuit rather than the zero-sequence one was chosen. The first and an evident one is that the zero-sequence circuit does not exist in the case of ungrounded faults. The second is that there is mutual coupling between zero-sequence components of two circuits in double-circuit transmission lines. The third
Fuzzy Logic Based Fault Detection and Classification of Unsynchronized Faults in Three Phase Double Circuit Transmission Lines

is that the zero-sequence parameters are not as accurate as the negative-sequence ones due to some unknown parameters that contribute to the zero-sequence circuits. Finally, it should be mentioned that the zero-sequence resistances cannot be assumed negligible in comparison to the zero-sequence reactances for developing a fault-location method since it might result in a large error. This assumption may, however, work well in other applications, such as fault detection and classification [12].

III. FAULT CLASSIFICATION AND IMPLEMENTATION OF FUZZY LOGIC APPROACH

The general process performed in a fuzzy logic approach is shown in Figure 4.

Fig 3. Fuzzy system.

The S1, S2 and S3 in Figure 2 are inputs to the fuzzy system, the calculation of these input variables using currents at one end of the system are given below. The ratios P1, P2 and P3 are calculated using post-fault currents, as follows:

\[
P_1 = \frac{\max\{abs(ia)\}}{\max\{abs(ib)\}}, \quad P_2 = \frac{\max\{abs(ib)\}}{\max\{abs(ic)\}}
\]

\[
P_3 = \frac{\max\{abs(ic)\}}{\max\{abs(ia)\}}
\]

Next, the values of S1, S2 and S3 are found out as follows:

\[
P_1(n) = \frac{P_1}{\max(P_1,P_2,P_3)}, \quad P_2(n) = \frac{P_2}{\max(P_1,P_2,P_3)}
\]

\[
P_3(n) = \frac{P_3}{\max(P_1,P_2,P_3)}
\]

Lastly, the differences of these P1(n), P2(n) and P3(n) are calculated as follows:

\[
S_1 = P_1(n) - P_2(n), \quad S_2 = P_2(n) - P_3(n), \quad S_3 = P_3(n) - P_1(n)
\]

A. Implementation Of Fuzzy Logic Approach

The Values of S1, S2 and S3 are three inputs to the fuzzy Classifier, used to classify nature of the fault; the general structure of Fuzzy Inference System (FIS) used in this technique is shown in Figure 5. For each input 3 triangular membership functions are chosen designated as Small g, Medium g and Large g. The membership function ranges for inputs are, value between -1.0 and -0.005 for Small g, value between 0.02 and 0.3 for Medium g, and value between 0.2 and 1.0 for Large g.

Fig 4. Fuzzy interface system

Fig 5. Triangular membership functions for inputs.

Fig 6. Triangular membership functions for outputs.

Rules to find nature of phase faults.

1. If (S1 is Small ph) and (S2 is Large ph) and (S3 is Small ph) then (trip output is AB)
2. If (S1 is Small ph) and (S2 is Small ph) and (S3 is Large ph) then (trip output is BC)
3. If (S1 is Large ph) and (S2 is Small ph) and (S3 is Small ph) then (trip output is CA)
4. If (S1 is Medium ph) and (S2 is Medium ph) and (S3 is Small ph) then (trip output is ABC)
5. If (S1 is Small ph) and (S2 is Medium ph) and (S3 is Medium ph) then (trip output is ABC)
6. If (S1 is Medium ph) and (S2 is Small ph) and (S3 is Medium ph) then (trip output is ABC)
7. If (S1 is Small ph) and (S2 is Small ph) and (S3 is Medium ph) then (trip output is ABC)

Fig 7 shows the triangular membership functions of the outputs designated as AG, BG, CG, ABG, BCG, and CAG Rules to find nature of ground faults using values of S1, S2 and S3.

1. If (S1 is Large g) and (S2 is Medium g) and (S3 is Small g) then (trip output is AG)
2. If (S1 is Small g) and (S2 is Large g) and (S3 is Medium g) then (trip output is BG)
3. If (S1 is Medium g) and (S2 is Small g) and (S3 is Large g) then (trip output is CG)
4. If (S1 is Small g) and (S2 is Large g) and (S3 is Small g) then (trip output is ABG)
5. If (S1 is Small g) and (S2 is Small g) and (S3 is Large g) then (trip output is BCG)
6. If (S1 is Large g) and (S2 is Small g) and (S3 is Small g) then (trip output is CAG)
8. If (S1 is Medium ph) and (S2 is Small ph) and (S3 is Small ph) then (trip output is ABC)
9. If (S1 is Small ph) and (S2 is Medium ph) and (S3 is Small ph) then (trip output is ABC)

![Triangular membership functions for inputs.](image1)

![Triangular membership functions for outputs.](image2)

IV. ACCURACY EVALUATION

Figs. 9–15 show the estimation errors of fault location for the different fault cases of Table I. The errors were calculated by

\[
\text{Estimation error\%} = \frac{\text{Actual location} - \text{Estimated location}}{\text{Total line length}} \times 100.
\]

<table>
<thead>
<tr>
<th>No.</th>
<th>Fault type</th>
<th>Fault resistance (Ω)</th>
<th>Actual fault location (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Ph-G</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>Ph-G</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>Ph-G</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Ph-Ph</td>
<td>5</td>
<td>[5..195] every 1 km</td>
</tr>
<tr>
<td>5</td>
<td>Ph-Ph</td>
<td>20</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Ph-Ph</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Ph-Ph-G</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Ph-Ph-G</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Ph-Ph-G</td>
<td>100</td>
<td></td>
</tr>
</tbody>
</table>

V. SIMULATION RESULTS

The results confirm that the proposed fault-location method is independent of the faulty pe and fault resistance. This can also be inferred from the discussion presented in Sections II and III. The small difference in the estimation errors when the faulty pe and fault resistance vary can be attributed to the errors generated by the instrument transformers (CVTs) and numerical calculation. It can be seen that the accuracy of the method will be quite high if the required parameters are close enough to their real values.

![Estimation errors for Case1 based on the lumped and PI model.](image3)

![Estimation errors for Case2 based on the lumped and PI model.](image4)

![Estimation error for Case3 based on the lumped and PI model.](image5)

![Estimation errors for Case4 based on the lumped and PI model.](image6)
Fuzzy Logic Based Fault Detection and Classification of Unsynchronized Faults in Three Phase Double Circuit Transmission Lines

Fuzzy detection based system (External Faults) The Fig.7 shows the design and graphical user interface for the fuzzy system that utilized for external fault detection and classification. The model consists of three inputs (Fig.8); the first is negative sequence of voltage (Va2) which has the range (0-7000) over four types of member functions (N, M, H, V.H). The second input is negative sequence of current (Ia2) which has a range (0-1800) over six membership functions (N, NN, N.M, N.H, M, H, V.H). The third input is the current of a phase which has ranges over (0-6000) with membership functions (N, M,N, N.H, M, H, V.H). The output of this system has nine membership functions which represent the types of faults that this system can detect and classify.

<table>
<thead>
<tr>
<th>Nature of Fault</th>
<th>S1</th>
<th>S2</th>
<th>S3</th>
</tr>
</thead>
<tbody>
<tr>
<td>AG</td>
<td>0.4721</td>
<td>0.6976</td>
<td>0.7071</td>
</tr>
<tr>
<td>BG</td>
<td>0.3117</td>
<td>0.6906</td>
<td>0.7078</td>
</tr>
<tr>
<td>CG</td>
<td>0.3131</td>
<td>0.2285</td>
<td>0.0316</td>
</tr>
<tr>
<td>ABG</td>
<td>0.5425</td>
<td>0.5391</td>
<td>0.5690</td>
</tr>
<tr>
<td>BCG</td>
<td>0.9721</td>
<td>0.0378</td>
<td>0.0222</td>
</tr>
<tr>
<td>CAG</td>
<td>0.3029</td>
<td>0.2432</td>
<td>0.6323</td>
</tr>
<tr>
<td>AB</td>
<td>0.7071</td>
<td>0.7071</td>
<td>0.7132</td>
</tr>
<tr>
<td>BC</td>
<td>0.0017</td>
<td>0.0028</td>
<td>0.0293</td>
</tr>
<tr>
<td>CA</td>
<td>0.7070</td>
<td>0.7068</td>
<td>0.7012</td>
</tr>
<tr>
<td>ABC</td>
<td>0.2521</td>
<td>0.2518</td>
<td>0.5784</td>
</tr>
</tbody>
</table>

Table III. Outputs for Fuzzy Logic at Rf=25Ω

<table>
<thead>
<tr>
<th>Nature of Fault</th>
<th>S1</th>
<th>S2</th>
<th>S3</th>
</tr>
</thead>
<tbody>
<tr>
<td>AG</td>
<td>0.4543</td>
<td>0.7009</td>
<td>0.7214</td>
</tr>
<tr>
<td>BG</td>
<td>0.3274</td>
<td>0.2262</td>
<td>0.0570</td>
</tr>
<tr>
<td>CG</td>
<td>0.3287</td>
<td>0.2309</td>
<td>0.0570</td>
</tr>
<tr>
<td>ABG</td>
<td>0.4600</td>
<td>0.5281</td>
<td>0.5685</td>
</tr>
<tr>
<td>BCG</td>
<td>0.7423</td>
<td>0.7504</td>
<td>0.5678</td>
</tr>
<tr>
<td>CAG</td>
<td>0.2896</td>
<td>0.1790</td>
<td>0.6142</td>
</tr>
<tr>
<td>AB</td>
<td>0.7071</td>
<td>0.7078</td>
<td>0.7114</td>
</tr>
<tr>
<td>BC</td>
<td>0.0019</td>
<td>0.0031</td>
<td>0.0604</td>
</tr>
<tr>
<td>CA</td>
<td>0.7069</td>
<td>0.7068</td>
<td>0.7020</td>
</tr>
<tr>
<td>ABC</td>
<td>0.2529</td>
<td>0.2500</td>
<td>0.5753</td>
</tr>
</tbody>
</table>
VI. CONCLUSION
A new fault-location and classification method for double-circuit transmission lines is proposed in this paper. It is a steady-state-based method based on the ratio of negative-sequence voltage magnitudes at both ends of the line. A fuzzy logic based technique has been presented for the identification and classification of faults. The proposed technique requires considering the post fault currents of all three phases at one end of the transmission system. This respective input fed to the fuzzy classifier systems to classify nature of the fault. Simulation has been performed by considering various conditions to satisfy the efficiency of the proposed technique. The major advantages of the proposed method can be summarized as follows, The evaluation results are encouraging and have shown the practicality of the proposed method for implementation in real applications. The proposed concept can be readily developed for single-circuit transmission lines as well.

- The proposed method is a purely analytical method, which effectively eliminates the computing burden to the relay.
- Another interesting feature of the proposed method is that it requires only the magnitudes of negative-sequence voltages, which completely removes the need for synchronization.
- The only type of fault that cannot be located by the proposed method is the three-phase fault which hardly occurs on transmission lines.

A. Appendix
The parameters of the simulated system are given as follows. The positive-, negative- and zero-sequence impedances behind relay Rs are

\[ Z_{1S} = Z_{2S} = 0.32 + j5.44 \ \Omega \]
\[ Z_{0S} = 0.8 + j4.48 \ \Omega. \]

The voltage of the source behind relay is

\[ V_S = 400 < 20^\circ \text{kV}. \]

The positive-, negative- and zero-sequence impedances behind relay are

\[ Z_{1R} = Z_{2R} = 0.48 + j8.32 \ \Omega \]
\[ Z_{0R} = 3.68 + j13.12 \ \Omega. \]

The voltage of source behind relay is

\[ V_R = 380 < 5^\circ \text{kV}. \]

The distributed model parameters of the double-circuit transmission line:
The positive-, negative-, and zero-sequence impedances are

\[ Z_{1L} = Z_{2L} = 0.0268 + j0.3139 \ \Omega/\text{km} \]
\[ Z_{0L} = 0.2102 + j1.1651 \ \Omega/\text{km}. \]

The mutual coupling capacitance between the zero-sequence circuits is

\[ C_{OM} = -2.1088 \text{nF/km}. \]

VII. REFERENCES