DEFINING FAULT LOCATION ON OVERHEAD LINES
ON THE BASE OF EMERGENCY SIGNALS RECORDER DATA

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The necessity of Defining Fault Location (DFL) on overhead lines appeared in XIX – XX-th centuries – at the beginning of Electric Power Networks (EPN) intensive development in all European countries and the USA. One of the first mentions of such procedure necessity is given in [1]. There is also given the analysis of expected results. DFL began developing practically in post-war years.

The theory and technique of DFL [2 – 4] have been developed but the number of technique and methodological issues still takes place and requires deep analysis. One of the most important issues is the increasing of DFL accuracy at using the method of DFL based on emergency mode parameters.

Nowadays the Emergency Signals Recorder (ESR) are widely used at EPN. This equipment allows to measure and register Arrays of Instantaneous Values (AIV) of electric signals – current and voltage, which include adequate information about physical phenomenon in network. This information can be used for development of more accurate DFL method.

Such method is based on mathematical formulation of overhead lines modes with line equations. The main idea of this method can be described by means of Fig. 1

![Fig. 1](image)

For defining the distances \( l_1 \), \( l_2 \) (see fig. 1) between the ends of line and short circuit place the line equations for long lines on base of hyperbolic functions written for both parts of the line according to the positive sequence network for “special” phase (for example for phase A) are used. Taking into account that \( l_2 = l - l_1 \), positive-phase-sequence voltage \( U_A \) at the short circuit point is defined with the following equations:

\[
U_{A1} = U_{A11} + l \left( 1 - \cos \theta \right) - \frac{U_{B1} + U_{C1}}{2} - \frac{U_{B2} + U_{C2}}{2} \quad \text{(1)}
\]

\[
U_{A1} = U_{A11} + l \left( 1 - \cos \theta \right) - \frac{U_{B1} + U_{C1}}{2} - \frac{U_{B2} + U_{C2}}{2} \quad \text{(2)}
\]

where \( U_{A11}, U_{A12} \) – vector values of phase A positive-phase-sequence voltages at the beginning and at the end of line; \( l \) – vector values of phase A positive-sequence currents at the beginning and at the end of line;

\[
\begin{align*}
Z_B &= \sqrt{\frac{1}{l}} + \frac{j}{l} \left( \frac{g_B + jh_B}{l} \right) = \sqrt{\frac{1}{l} \gamma_0} \quad \text{– characteristic impedance of line;} \\
\gamma_0 &= \sqrt{\frac{1}{l} + \frac{j}{l} \left( \frac{g_B + jh_B}{l} \right) = \sqrt{\frac{1}{l} \gamma_0} \quad \text{– propagation constant of electromagnetic mode in line.}
\end{align*}
\]

Based on the evident equality of equations (1, 2) left parts there can be written an equation (3), that allows to define the distance \( l_1 \) between the beginning of the line and short circuit place:

\[
0 = U_{A11} + l \left( 1 - \cos \theta \right) - \frac{U_{B1} + U_{C1}}{2} - \frac{U_{B2} + U_{C2}}{2} \quad \text{(3)}
\]

The vector values of phase A positive-sequence voltages and currents, used in the equations (1, 2) can be defined accordingly to AIV of voltages and currents be means of generalized vectors [5]

\[
F_{A,i} = \sqrt{2} F_{A,i} e^{i \phi_{A,i}}, \quad i = 1, 2;
\]

\[
F_{A1} = \frac{1}{N} \sum_{j=1}^{N} f_{A,j} e^{i \phi_{A,j}}, \quad i = 1, 2;
\]

\[
\phi_{A,i} = \arccos \left( \frac{1}{N} \sum_{j=1}^{N} \left( f_{A,i} e^{i \phi_{A,j}} \right) \right) - \text{correspondently AIV and vector module of voltage or current, with which the corner axis of reference is combined.}
\]

In its turn, the AIV of phase A positive-sequence voltages and currents can be defined from voltages and currents of each phase AIV (registered with ESR at the beginning and at the end of line) by means of a known way of unsymmetrical three-phase vectors \( F_a, F_b, F_c \) decomposition to symmetrical components of forward \( F_{A1} \), reverse \( F_{A2} \) and zero-sequences \( F_0 \) [6], which obviously can be applied to AIV of voltages and currents:

\[
f_{a,i} = \frac{1}{3} \left( f_{a1} e^{i \phi_{A1}} + f_{a2} e^{i \phi_{A2}} + a^2 f_{a3} e^{i \phi_{A3}} \right), \quad \text{where } a = e^{i 120^\circ}, a^2 = e^{i 420^\circ} \text{ – operators of turn.}
\]

Thus accordingly to the equation (4) there is data shift in arrays of phase B and C voltages and currents at angle 120º or 240º, that are defined with operators \( a, a^2 \) (fig. 2, a, b).
Fig. 2. Data shift in arrays of voltages: a) of phase B, b) of phase C

The accuracy of described DFL method was verified by means of bundled software Mathcad in terms of two single-circuit overhead lines with length 600 and 8 km, nominal voltage 500 kV and total load $S=250+j105$ MVA. Linear electrical parameters are equal and are presented in the Table 1.

Table 1. Linear electrical parameters

<table>
<thead>
<tr>
<th>$r_0$, Om/km</th>
<th>$x_0$, Om/km</th>
<th>$g_0$, $10^{-9}$ S/km</th>
<th>$b_0$, $10^{-6}$ S/km</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.022</td>
<td>0.301</td>
<td>7.333</td>
<td>3.694</td>
</tr>
</tbody>
</table>

The calculations were completed for all types of short circuit at the distance 200 and 2 km accordingly to lines with lengths 600 and 8 km. The AIV of voltages and currents in all phases were calculated at the beginning and at the end of lines at discretization interval $\Delta t = 0.317$ ms and at correspond quantity of readout on the period $N=63$. The calculation results of short circuit place by means of defined AIV are presented in the Table 2.

Table 2. The calculation results of short circuit place

<table>
<thead>
<tr>
<th>SC type</th>
<th>$l$, km</th>
<th>Error, %</th>
<th>$l$, km</th>
<th>Error, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>K$^{(1)}$</td>
<td>200</td>
<td>0</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>K$^{(2)}$</td>
<td>200</td>
<td>0</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>K$^{(1,1)}$</td>
<td>200</td>
<td>0</td>
<td>2</td>
<td>0</td>
</tr>
</tbody>
</table>

The analysis of calculations results shows the absence of a methodical error in considered algorithm at a discretization interval $\Delta t = 0.317$ ms.

One of the main reasons for error in definition of a place of damage by offered algorithm is using in the equations (1, 2) inexact values of linear electrical parameters which are usually accepted from reference date. For decreasing of this error it is offered to use in the equations (1, 2) the specified values of linear electrical parameters [7] calculated on base of electrical parameters registered in preemergency mode.

In summary it is worth to notice that the further development of DFL technique based on wide use of the equations of a long line, in the long term can lead to construction of new high-precision equipment for defining fault location on emergency mode electrical parameters.

References

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