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METODOLOGICAL ASPECTS OF IDENTIFICATION OF TWO-PHASE OPEN FAULT LOCATION ON OVERHEAD POWER LINE

МЕТОД ОПРЕДЕЛЕНИЯ МЕСТА ПОВРЕЖДЕНИЯ ДВУХ ФАЗ НА ВОЗДУШНОЙ ЛИНИИ ЭЛЕКТРОПЕРЕДАЧИ

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Приведено описание метода определения места обрыва двух фаз воздушной линии электропередачи. Показано, что повышенная точность метода достигается за счет учета пространственной распределенности параметров линии, а также за счет использования в алгоритмах уточненных погонных сопротивлений и проводимостей линии, предварительно определенных по параметрам предаварийного режима. В качестве исходных данных используются массивы мгновенных значений электрических величин – токов и напряжений, измеренных по концам линии с помощью регистраторов аварийных сигналов, а в качестве математического аппарата – уравнения длинной линии.

The article introduces the results of methodological aspects development of two-phase open fault location identification on overhead power line based on preliminary identification of line attenuation resistance and conductivity in prefault conditions. The fault location identification technique with allowance for line distributed parameters is applied. Current and voltage instantaneous values are used by means of data and long-distance transmission line equations are used as mathematical tool.

Ключевые слова:
Воздушная линия электропередачи, массивы мгновенных значений токов и напряжений, обрыв двух фаз, место повреждения, прямая и обратная последовательности, симметричные составляющие токов и напряжений, уравнения длинной линии.

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Key words:
Overhead power line, current and voltage instantaneous values, two-phase open fault, fault location, direct and reverse sequences, current and voltage symmetrical components, long-distance transmission line equations.

In Russia there are operated High Voltage Overhead Lines (OHL) with bar wires that are simultaneously impacted with static and dynamic loads. The additional dynamic stress do not appear in wires and structural element of OHL under static loads while the affect of dynamic loads leads to wires vibration that can result in dangerous resonance accompanied by a sudden mechanical stress increase.

Danger effect of dynamic loads wires depends on vibration frequency and duration; static loads effect depends on coating of ice mass and wind strength. Combined action of both load types increases significantly the risk of OHL break. So one of the most important tasks of line maintenance services at electric power networks is a rapid and accurate identification of fault location and restoration activities.

It should be noted that the methods of identifying the place of short circuit at OHL are highly elaborated while the ideology of determining the line break location is very poor developed and the existing methods have some deficiency.

For instance, in [1] it is suggested to diagnose single or two-phase open fault location using the off-load line values, i. e. capacitive currents measured at their transient conditions or in post-emergency conditions. The limitations of the method are: its multistage character; neglect of the OHL distribution parameters; inaccurate location under the open fault.

The OHL single or two-phase open fault can also be identified by monitoring the network with the master device installed at the sub-transmission substation. The device collects preliminary data from the network sections integrity scanning the subordinate devices. The use of the method is limited because it can identify only the network section where the single or two-phase open fault is occurred, not the exact location of the phase open fault [2].

The authors have developed and approbated the methods of identifying the overhead power line attenuation parameters in prefault conditions and the methods of determining the place of short circuit at OHL of arbitrary length based on emergency mode [3, 4]. The fundamental equations for a long-distance line were used as mathematical apparatus [5].

Therefore the paper considers the idea of identifying the location of two-phase open fault at overhead line. Current and voltage instantaneous values registered with the Emergency Signal Recorders widely used in power networks were decided to be used on the base of the method. These values include adequate information about physical phenomenon in power network.

The two-phase open fault is referred to the serial asymmetry which can be consequence of the transverse asymmetry. Under these circumstances the relay protection deenergizes broken down phases and only «the special» phase is in service.

This process is calculated by means of the symmetrical component method [6]. According to this method the asymmetry obtains lumped mode and the rest part of the network is constructively symmetrical (Fig. 1). Index «*L*» is the symbol of serial asymmetry; «ΔU_L» is voltage drop at the asymmetrical part of the network regarding serial asymmetry terminals «*L*-*L*′».

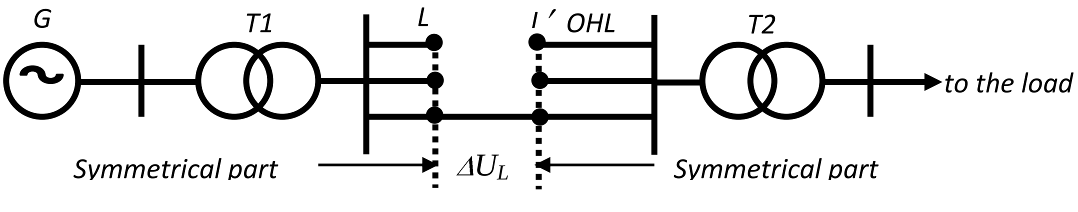

Fig. 1. Serial asymmetry

The idea of two-phase open fault location identifying at OHL can be explained by the example of *B*- and *C*-phase open fault (Fig. 2). Obviously in this case the phase *A* is considered as «the special» phase.

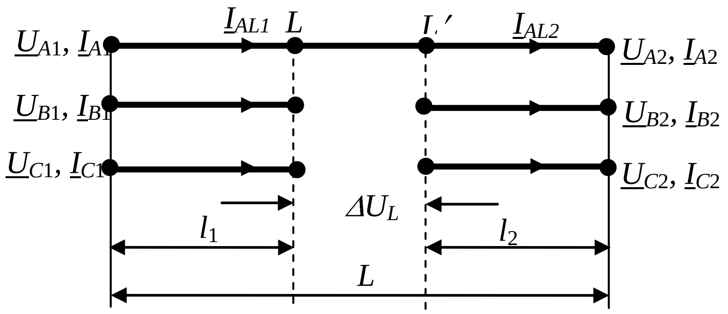

Fig. 2. *B*- and *C*-phase open fault

Boundary relations (1) under two-phase open fault location according to conditions which are introduced on Fig. 2:

$$\left.\begin{aligned} \Delta\underline{U}_{AL} &= 0; \\ \underline{I}_{BL} &= 0; \\ \underline{I}_{CL} &= 0. \end{aligned}\right\}. \tag{1}$$

These relations lead to ratio (2): under two-phase open fault the positive sequence current at the place of damage equals to the negative sequence current at the place of damage for «the special» phase (*A* phase in this example):

$$\underline{I}_{A1,L} = \underline{I}_{A2,L}\,. \tag{2}$$

The current at the open fault location flowing from the beginning of the line equals to the current flowing to the end of the line (3):

$$\underline{I}_{AL} = \underline{I}_{AL1} = \underline{I}_{AL2}\,. \tag{3}$$

Generally the current at the open fault location relative to the beginning and the end of the line can be expressed in terms of the long-distance transmission line equations in the hyperbolic function format (4, 5):

$$\underline{I}_{AL} = -\frac{\underline{U}_{A1}}{\underline{Z}_{\mathrm{B}}}\mathrm{sh}\;\; \underline{\gamma}_0 l_1 \;\; + \underline{I}_{A1}\mathrm{ch}\;\; \underline{\gamma}_0 l_1 \;\; ; \tag{4}$$

$$\underline{I}_{AL} = \frac{\underline{U}_{A2}}{\underline{Z}_{\mathrm{B}}}\mathrm{sh}\;\; \underline{\gamma}_0 l_2 \;\; + \underline{I}_{A2}\mathrm{ch}\;\; \underline{\gamma}_0 l_2 \;\; , \tag{5}$$

where $\underline{Z}_{\mathrm{B}}$ is wave impedance; $\underline{\gamma}_0$ is the constant of electromagnetic wave propagation (6).

$$\underline{Z}_{\mathrm{B}} = \sqrt{\frac{\underline{z}_0}{\underline{y}_0}}; \quad \underline{\gamma}_0 = \sqrt{\underline{z}_0 \cdot \underline{y}_0}. \tag{6}$$

Rewriting equations (4), (5) respectively to positive sequence current $\underline{I}_{A1,L}$ leads to relations (7), (8):

$$\underline{I}_{A1,L} = -\frac{\underline{U}_{A1,1}}{\underline{Z}_{\mathrm{B}}}\mathrm{sh}\;\; \underline{\gamma}_0 l_1 \;\; + \underline{I}_{A1,1}\mathrm{ch}\;\; \underline{\gamma}_0 l_1 \;\; ; \tag{7}$$

$$\underline{I}_{A1,L} = \frac{\underline{U}_{A1,2}}{\underline{Z}_{\mathrm{B}}}\mathrm{sh}\;\; \underline{\gamma}_0 l_2 \;\; + \underline{I}_{A1,2}\mathrm{ch}\;\; \underline{\gamma}_0 l_2 \;\; . \tag{8}$$

Taken into account that $l_2 = L - l_1$ the expressions (7) and (8) will be transformed to (9):

$$-\frac{\underline{U}_{A1,1}}{\underline{Z}_{\mathrm{B}}}\mathrm{sh}\;\; \underline{\gamma}_0 l_1 \;\; + \underline{I}_{A1,1}\mathrm{ch}\;\; \underline{\gamma}_0 l_1 \;\; - \frac{\underline{U}_{A1,2}}{\underline{Z}_{\mathrm{B}}}\mathrm{sh}\;\; \underline{\gamma}_0 (L - l_1) \;\; - \underline{I}_{A1,2}\mathrm{ch}\;\; \underline{\gamma}_0 (L - l_1) \;\; = 0\,, \tag{9}$$

where $\underline{U}_{A1,1} / \underline{I}_{A1,1}$ are the vector values of *A* phase positive sequence voltage/current at the line sending end; $\underline{U}_{A1,2} / \underline{I}_{A1,2}$ are the vector values of *A* phase positive sequence voltage/current at the end-of-line.

The trigonometric solution of equation (9) results in formula (10) for defining location of OHL two-phase open fault:

$$l_1 = \frac{1}{\underline{\gamma}_0} \operatorname{arth}\left(\frac{\underline{I}_{A1,1}\underline{Z}_{\text{B}} - \underline{U}_{A1,2}\text{sh}\ \ \underline{\gamma}_0 L\ \ - \underline{I}_{A1,2}\underline{Z}_{\text{B}}\text{ch}\ \ \underline{\gamma}_0 L}{\underline{U}_{A1,1} - \underline{U}_{A1,2}\text{ch}\ \ \underline{\gamma}_0 L\ \ - \underline{I}_{A1,2}\underline{Z}_{\text{B}}\text{sh}\ \ \underline{\gamma}_0 L} \right). \tag{10}$$

Current and voltage vectors used in expression (10) can be defined from the *A*, *B*, *C* phase current and voltage vectors at the sending end and at the end-of-line $\underline{I}_{A1}$, $\underline{I}_{B1}$, $\underline{I}_{C1}$, $\underline{I}_{A2}$, $\underline{I}_{B2}$, $\underline{I}_{C2}$, $\underline{U}_{A1}$, $\underline{U}_{B1}$, $\underline{U}_{C1}$, $\underline{U}_{A2}$, $\underline{U}_{B2}$, $\underline{U}_{C2}$ by means of the symmetrical component ratio (11–14):

$$\underline{I}_{A1,1} = \frac{1}{3}\ \underline{I}_{A,1} + a\underline{\text{I}}_{B,1} + a^2\underline{\text{I}}_{C,1}\ \ ; \tag{11}$$

$$\underline{I}_{A1,2} = \frac{\mathbf{1}}{\mathbf{3}}\ \underline{I}_{A,2} + a\underline{I}_{B,2} + a^{\mathbf{2}}\underline{I}_{C,2}\ \ ; \tag{12}$$

$$\underline{U}_{A\mathbf{1},\mathbf{1}} = \frac{\mathbf{1}}{\mathbf{3}}\ \underline{U}_{A,\mathbf{1}} + a\underline{U}_{B,\mathbf{1}} + a^2\underline{U}_{C,\mathbf{1}}\ \ ; \tag{13}$$

$$\underline{U}_{A\mathbf{1},\mathbf{2}} = \frac{\mathbf{1}}{\mathbf{3}}\ \underline{U}_{A,\mathbf{2}} + a\underline{U}_{B,\mathbf{2}} + a^2\underline{U}_{C,\mathbf{2}}\ \ . \tag{14}$$

The vector values of *A*, *B*, *C* phase currents and voltages in the beginning and at the end of the line $\underline{I}_{A1}$, $\underline{I}_{B1}$, $\underline{I}_{C1}$, $\underline{I}_{A2}$, $\underline{I}_{B2}$, $\underline{I}_{C2}$, $\underline{U}_{A1}$, $\underline{U}_{B1}$, $\underline{U}_{C1}$, $\underline{U}_{A2}$, $\underline{U}_{B2}$, $\underline{U}_{C2}$ can be identified using the generalized vectors [7] from correspondent instantaneous values: $i_{A1}(t_{\text{j}})$, $i_{B1}(t_{\text{j}})$, $i_{C1}(t_{\text{j}})$, $i_{A2}(t_{\text{j}})$, $i_{B2}(t_{\text{j}})$, $i_{C2}(t_{\text{j}})$, $u_{A1}(t_{\text{j}})$, $u_{B1}(t_{\text{j}})$, $u_{C1}(t_{\text{j}})$, $u_{A2}(t_{\text{j}})$, $u_{B2}(t_{\text{j}})$, $u_{C2}(t_{\text{j}})$) registered by the Emergency Signal Recorders (15):

$$\underline{F}_1 = \sqrt{2}F_1 e^{j\varphi_1}\ ;\ F_1 = \sqrt{\frac{1}{N}\sum_{j=1}^{2} f_1^{\,2}(t_j)}\ ;\ \varphi_1 = \arccos\left(\frac{\frac{1}{N}\sum_{j=1}^{N}\ f_1(t_j)\cdot h_1(t_j)}{F_1 \cdot H_1} \right), \tag{15}$$

where $h_1(t_{\text{j}})$, H_1, $i = \overline{1,2}$ are the instantaneous and absolute values of voltage or current correspondingly; $N = T/\Delta t$ is the massif scale numbering; T is the signal cycle; Δt is the discretization interval.

The described method for identifying the location of OHL two-phase open fault was tested by the examples of 500 kV single-circuits OHL with 8 and 600 km length. Both lines are completed by splitted steel-cored aluminum conductors. The horizontal distance among the centre of splitted phases is 12 m. The splitted conductors obtain equilateral-triangle arrangement. The side of a triangle is 40 cm. The conductor diameter is 30,2 mm.

Each line transmits power to the load $\underline{S}$ = 600+*j*250 MVA. The reference data of the line parameters are given in the Table 1.

Table 1. The reference data of the line parameters

L, km	r_0, Ohm/km	x_0, Ohm/km	b_0, 10^{-9} 1/Ohm·km	g_0, 10^{-6} 1/Ohm·km
600	0,022	0,301	7,333	3,694

Two cases were considered: two-phase open fault of 8 km length line at 2 km and two-phase open fault of 600 km length line at 200 km. Firstly the instantaneous values of current and voltage in the beginning and in the end of lines were calculated by discretization interval Δt =0,1 ms. Then the location of open fault were identified in both variants according to the method described above. Table 2 introduces the calculation results.

Table 2. The calculation results

Characteristics, km	l_1, km	Accuracy, %
l = 600, l_1 = 200	200	0
l = 8, l_1 = 2	2	0

The analysis of calculation results shows the absence of a methodical error in the considered algorithm at the discretization interval Δt = 0,1 ms.

Conclusions

1. The suggested method is applicable to stretched lines as it considers the dispersion of line parameters by means of using fundamental equations for a long-distance line.
2. The method demonstrates high accuracy at defining location of overhead line two phase open fault.
3. One of the main reasons for an error in fault location identification by the offered algorithm is the application of inexact values of line parameters which are usually taken from the reference data in the equations (10). For decreasing this error it is offered to use in the equation (10) the real line attenuation parameters calculated on the base of current and voltage instantaneous values registered by the Emergency Signal Recorders in prefault conditions.

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