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A neural space vector fault location for parallel double-circuit distribution lines

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Abstract

A new approach to fault location for parallel double-circuit distribution power lines is presented. This approach uses the Clarke–Concordia transformation and an artificial neural network based learning algorithm. The α, β, 0 components of double line currents resulting from the Clarke–Concordia transformation are used to characterize different states of the system. The neural network is trained to map the non-linear relationship existing between fault location and characteristic eigenvalue. The proposed approach is able to identify and to locate different types of faults such as: phase-to-earth, phase-to-phase, two-phase-to-earth and three-phase. Using the eigenvalue as neural network inputs the proposed algorithm locates the fault distance. Results are presented which shows the effectiveness of the proposed algorithm for a correct fault location on a parallel double-circuit distribution line.

Keywords: Artificial neural networks; Clarke–Concordia transform; Eigenvalue; Fault location; Parallel double-circuit distribution lines

1. Introduction

The continuity of service is one of the most important issues related with the quality of service in the field of electrical distribution power networks. As a consequence, fault location assumes an important role allowing a fast maintenance response.

Some of the fault location algorithms consist mainly in computing impedance fault line, based on voltage and current phasors data. Thus, a relationship between impedance and fault distance can be established, assuming as previously known line parameters [1]. Other fault location algorithms use voltage and current forward and backward travelling waves, which change their shape at a discontinuity, therefore, allowing fault location [2].

The use of microprocessor technology within protection devices allows the extension to other functions such as, for instance, fault diagnosis, network control and monitoring. Soft computing techniques within digital signal processing can be used to recognize the type and location of the fault. In particular artificial neural networks (ANN) can be applied in association to phasor computation [3,4], or used as a pattern classifier to improve the performance of a distance relay [5,6]. Other methods, such as the Fuzzy-Neuro technologies [7], are able to incorporate the uncertainties associated with model power systems and fault impedance calculation.

The usual distribution line model (short lines) is the lumped-parameter model, applying symmetrical components on phasor-based algorithms [8].

The proposed methodology combines the Clarke–Concordia Transformation and the eigenvalue approach [9,10] with soft computing techniques for accurate characterization of the fault. The main purpose of the global algorithm is to locate the distance and the line where the fault occurs. Furthermore it will identify the following types of fault: phase-to-earth, phase-to-phase, two-phase-to-earth and three-phase. This methodology has been applied to a parallel double-circuit distribution line as in Fig. 1. Fault condition simulations were established on 'Matlab/Simulink' software.

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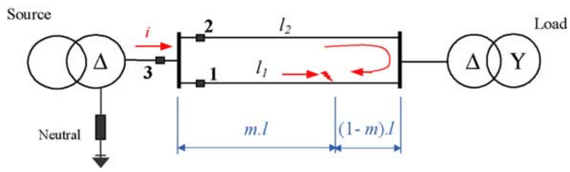

Fig. 1. Parallel double-circuit distribution diagram.

To study the effectiveness of the proposed method, a model for the physical components of the system (source, parallel double-circuit line and load) is considered. This system model uses lumped parameters and adopts the differential equations representing each of the possible fault or steady-state situations.

It remains as important characteristic of this method, that it is enough to consider only three current signals (it is not necessary to know voltage signals). Besides that, the establishment of fault location can be defined after the line protection operates.

2. System model

For the system model of the parallel double-circuit distribution line network (Fig. 1) the following was considered:

- Voltage source corresponding to the power substation transformers HV/MV. It is represented by the three phase system voltages related to the secondary winding transformer impedances (delta connections). Neutral points are earthed assumed;
- Parallel double-circuit distribution lines (three phase conductor underground cables). They are represented by equivalent *RL* schemes, with lumped parameters considering cable capacitances and mutual inductances neglected;
- The load is assumed as symmetrical balanced and located on a defined point. It corresponds to the power distribution substation transformer (MV/LV) and is represented by the primary delta winding.

For the simulation process, a system model based on the differential equations was used. These equations are obtained from the Kirchoff laws using the principle of superimposition.

The system model, which represents the different kinds of fault situations, can be simply represented by the following state-space equations:

$$\dot{x} = Ax + Bu \quad y = Cx \tag{1}$$

where A, B, and $\mathbf{C}$ are the related matrices.

The analyses takes into account system protections located on point '**1**' (line l_1) and point '**2**' (line l_2).

A system protection on point '**3**' it is similar to consider a unique radial distribution line, with no possibility to identify the line where the fault probably occurs.

2.1. Steady state

Current flowing through lines l_1 and l_2 are identical. The steady state situation for each line can be represented by:

$$\frac{\mathrm{d}}{\mathrm{d}t}\boldsymbol{I}(i)_S = \boldsymbol{A}(i)\boldsymbol{I}(i)_S + \boldsymbol{B}(i)\boldsymbol{U}_{xy} \quad \boldsymbol{I}(i) = \boldsymbol{C}\boldsymbol{I}(i)_S \tag{2}$$

where i and li are the line references, $\boldsymbol{I}(i)_S$ and $\boldsymbol{I}(i)$ are the source and line currents, $\boldsymbol{U}_{xy}$ are line to line source voltages, and

$$\boldsymbol{A}(i) = -\begin{bmatrix} \dfrac{R(li)+k_{12}R_C}{L(li)+k_{12}L_C} & 0 & 0 \\ 0 & \dfrac{R(li)+k_{23}R_{Ci}}{L(li)+k_{23}L_{Ci}} & 0 \\ 0 & 0 & \dfrac{R(li)+k_{31}R_{Ci}}{L(li)+k_{31}L_{Ci}} \end{bmatrix} \tag{3}$$

$$\boldsymbol{B}(i) = \begin{bmatrix} \dfrac{1}{L(li)+k_{12}L_{Ci}} & 0 & 0 \\ 0 & \dfrac{1}{L(li)+k_{23}L_{Ci}} & 0 \\ 0 & 0 & \dfrac{1}{L(li)+k_{31}L_{Ci}} \end{bmatrix} \tag{4}$$

with

$$\begin{cases} R(li) = 2l_{li}R_{li} + R_S \\ L(li) = 2l_{li}L_{li} + L_S \end{cases} \tag{5}$$

and

$$\boldsymbol{C} = \begin{bmatrix} 1 & 0 & -1 \\ -1 & 1 & 0 \\ 0 & -1 & 1 \end{bmatrix} \tag{6}$$

It is important to verify that the load resistance and load reactance is affected by factors k_{12}, k_{23}, k_{31}.

For maximum line capacity and symmetrical load, those factors are $k_{12}=k_{23}=k_{31}=1$.

2.2. Phase-to-earth and two-phase-to-earth fault

Phase-to-earth fault and two-phase-to-earth fault currents, $\boldsymbol{I}(i)_d$, are expressed by:

$$\frac{\mathrm{d}}{\mathrm{d}t}\boldsymbol{I}(i)_d = \boldsymbol{A}(i)_d\boldsymbol{I}(i)_d + \boldsymbol{B}(i)_d\boldsymbol{U}_{0x} \tag{7}$$

where $\boldsymbol{U}_{0x}$ are line to neutral voltages, $\boldsymbol{A}(i)_d$ and $\boldsymbol{B}(i)_d$ are similar to (3) and (4) but $R_{(li)}$; $L_{(li)}$ is replaced by (8) and (9), assuming fault on line 1:

Line 1 ($i=1$)

$$\begin{cases} R_{\mathrm{def}}(1) = ml_1R_{l1} + R_S + R_N + R_d \\ L_{\mathrm{def}}(1) = ml_1L_{l1} + L_S + L_N + L_d \end{cases} \tag{8}$$