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Fast Earth Fault Location by Analysing the Character of the Initial Processes

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Introduction

Earth fault is a frequent defect in the insulated or compensated networks. Automatic, fast and reliable spotting of the earth fault in such networks is a complicated task because of unstable fault parameters. Such situation leads to damaging the insulation of neighbour feeders, prolonged damage repairing time, improper staff actions that may cause new insulation damages [1, 2].

The conventional relays based on measuring steady fault current value often give us a case of wrong fault identification because of negligible steady current value that significantly depends on ground resistivity and network pattern [3]. In this case, the transient period just after the fault has appeared is more informative and has been used for the development of a new fault location algorithm which is based on the initial processes analysis. The algorithm has been successfully tested for low and high impedance, intermittent and non-intermittent earth faults spotting in different pattern insulated or compensated networks.

Other authors also have researched the overvoltage problems in their works by using different methods and algorithms [4–6].

The algorithm is based on special nano-second fault spotting (NSFS) technology which includes three main keystones:

- Nanosecond type recording digital steps are used for recording and analysing transients afterwards;
- Special digital filters are applied to reduce noises and to cut barren sections in the recorded files together with developing of available data for fault spotting;
- Special optimizing procedures are adjusted to search faulted feeder and fault point together with revising network surge parameters.

If for the solution of the problem it is enough to use short recorded proceeding in time, then the earth fault spotting becomes a numerical modelling of the very fast electromagnetic transients. It requires using short digital steps, increasing the velocity of recordings and expanding the diapason of measured values.

The length of electrical lines in the network and the velocity of electromagnetic waves arbitrate recording time. Usually it takes from some microseconds till some hundreds of microseconds. But the most informative data traces on the front of recorded currents or voltages. It sometimes allows to use recordings short enough and to get acceptable recognition.

Some example results of the considered measurements have been presented [7–9].

Short recordings gain some advantages in numerical modelling of transformers and inductors, simulating of fronts of the waves in overhead lines, to simplify algorithm of transients calculation in network model and to use various digital filters. Some of these topics are reviewed in this paper.

Modelling peculiarities of the initial earth fault processes

Densities of magnetic fluxes below ground in case of the overhead line depend on the strength of the currents in line wires, ground resistivity and frequency spectrum in transients. Acceptable and light assumptions which are used allow to simulate fluxes in homogenous ground with one layer of soil by digital filter with Frobenues matrix [10]. But in reality the ground consists of some layers of soil with different values of ground resistivity.

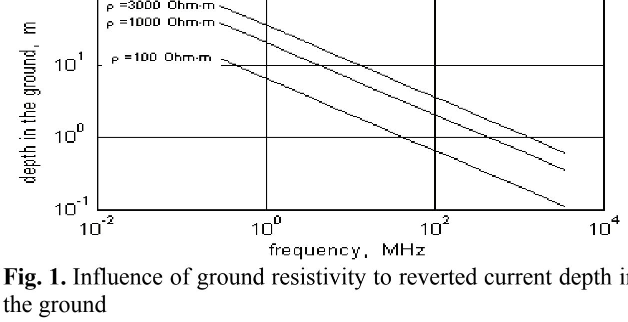

Fig. 1. Influence of ground resistivity to reverted current depth in the ground

It complicates the numerical modelling if the range of the frequencies is very wide. If the frequency becomes lower, fluxes get into the lower layer of the soil.

Fig. 1 shows how the depth of the reverted current (the equivalent model of the distributed currents in the ground) depends on the current frequency for different resistivity of the ground.

The upper layer usually has the lowest ground resistivity, and the next layer has much higher value. As it follows from Fig. 1, in the case of 100 Ω m, when current frequency is higher than 1 MHz, the reverted current and more intensive fluxes occur in the surface sheet that is less than 10 meters. If the second layer of the soil lies deeper, the influence of fluxes in it will be negligible. In this case the current front in transients is less disturbed by these fluxes if the record takes less than some microseconds as it is shown in Fig. 2.

Wave front is obtained for zero sequence by numerical modelling in 2 km 20 kV overhead line with Raven type of towers (height for all conductors, measured at a tower, is 8.0 meters with horizontal spacing between phases – 1.2 meters). The upper layer has ground resistivity 100 Ω m and the next layer under 10 meters – 1000 Ω m. Fig. 2 shows that up till 10 μs curves of the front differ in values less than in 5 percent.

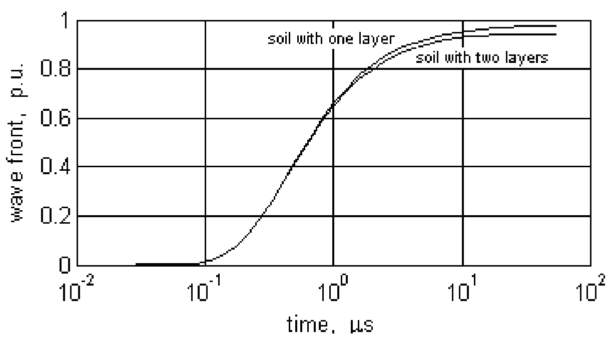

Fig. 2. Transient characteristics of the wave front in the overhead line if ground is of one soil layer and of two soil layers

Protective rope in the overhead lines is used to protect insulation of lines if the lines are charged by lightning. In a case of 35 kV line, protective ropes are grounded at the approaches to the substation to protect the insulation of the substation equipment charged by lightning overvoltages with a steep front. Normally, the rope near the substation is grounded in all towers. The grounding of the rope extremely changes shape of the wave front (Fig. 3).

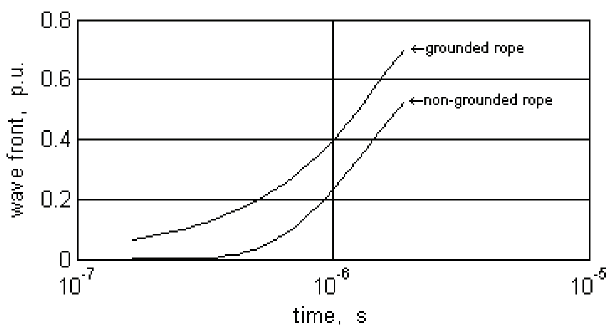

Fig. 3. The influence of the protective rope grounding to the shape of wave front in the overhead line of zero sequence

That shows the necessity to use multi-conductor model for the lines at the approaches to the substation in numerical modelling of the fast transients [11]. Actually, the geometrical location of wires on the towers also has some influence on the shape of the wave front.

The most non-linearity in numerical modelling of transients has transformers and inductors with a ferromagnetic core inside. It seriously complicates the model by the necessity to use special numerical methods for solving differential equations of the transformers and inductors. If the model is applied in any recognition device, the computation of the equations takes too much time and so limits the application field of such attachments. Numerical modelling of very fast transients allows to escape solving differential equations of the transformers and inductors. Inductivity of this equipment together with surge impedances of the lines form transfer function on the area of frequency domain that is far enough from spectrum area of fast transients. Typical amplitude-frequencies transfer functions of transformer currents are shown in Fig. 4, when 1 or 10 lines are connected to substation nods.

Such disposition of transfer functions allows to use linear type of the inductor mathematical model even if it is necessary to include additional inductor into numerical model of the transients. The most convenient way in that case is to use simplified digital filter.

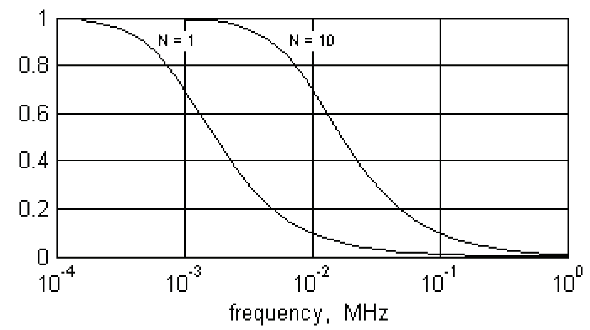

Fig. 4. Amplitude-frequencies transfer functions of transformer currents if the substation has 1 or 10 lines

Numerical method

Geometrical location of wires on the tower of overhead lines influences the wave front shape in fast transients. Lines equations in D'Alamber form are used in modal coordinates:

$$\begin{cases} \boldsymbol{W}_{\mathrm{S}}^{-1}\boldsymbol{U}_{\mathrm{S}} + \boldsymbol{I}_{\mathrm{S}} = \boldsymbol{S}_{\mathrm{S}} \times \boldsymbol{F}_{\mathrm{S}}\,; \\ \boldsymbol{W}_{\mathrm{S}}^{-1}\boldsymbol{U}_{\mathrm{S}} + \boldsymbol{I}_{\mathrm{S}} = \boldsymbol{S}_{\mathrm{S}}^{-}\,; \end{cases} \tag{1}$$

here $\boldsymbol{U}_{\mathrm{S}}$ and $\boldsymbol{I}_{\mathrm{S}}$ are vector-matrixes: voltages of the nod and currents in the line in modal coordinates; $\boldsymbol{S}_{\mathrm{S}}$ and $\boldsymbol{S}_{\mathrm{S}}^{-}$ are current waves in modal coordinates; $\boldsymbol{S}_{\mathrm{S}} \times \boldsymbol{F}_{\mathrm{S}}$ - convolution of the wave coming from the opposite end of the line and dispersion function; $\boldsymbol{W}_{\mathrm{S}}$ - diagonal matrix of surge impedances:

$$W_s = \Gamma^{-1} \cdot T_u^{-1} \cdot L \cdot T_i\,; \tag{2}$$

$$\begin{cases} \Gamma^2 = T_u^{-1} \cdot L \cdot C \cdot T_u\,; \\ \Gamma^2 = T_i^{-1} \cdot C \cdot L \cdot T_i\,; \end{cases} \tag{3}$$

here $\boldsymbol{L}$ and $\boldsymbol{C}$ are square matrixes of specific inductances and admittances of the line; $\boldsymbol{T}_u$ and $\boldsymbol{T}_i$ eigenvectors are used to produce a diagonal matrixes $\boldsymbol{U}_s$ and $\boldsymbol{I}_s$.

The dispersion function in time domain in any modal coordinate is found by using numerical calculation of integral

$$h(t) = \frac{2}{\pi}\int_0^\infty \mathrm{Re}D(\mathrm{j}\omega)\frac{\sin(\omega t)}{\omega}\mathrm{d}\omega\,; \tag{4}$$

here $D(\mathrm{j}\omega)$ is dispersion function of the wave in frequency domain.

Numerical calculation is realized by next formulas:

$$h_m = \sum_{i=1}^{N} y_i \frac{\sin(x_i t_m)}{x_i}\Delta_i\,; \tag{5}$$

$$\Delta_i = \frac{4\cdot 10^{-8}}{t_m}\sqrt{\frac{e^i}{N}}\,; \tag{6}$$

$$y_i = z_{k-1} + \frac{z_k - z_{k-1}}{\log\left(\omega_k / \omega_{k-1}\right)}\log\left(2\pi \cdot x_i / \omega_{k-1}\right); \tag{7}$$

$$z_k = \mathrm{Re}\,D(\mathrm{j}x_k); \quad k \in \{1,\ldots,K\}\,; \tag{8}$$

$$x_i = x_o + \sum_{n=1}^{i}\Delta_n\,. \tag{9}$$

The algorithm gives acceptable convergence and precision of the results. It is applied in special phase to earth fault location devices for isolated or compensated networks.

Fig. 5 shows waves front of zero sequence, which were calculated and simulated using digital fault simulator, after fault in 10 kV line with various branches to all energy consumers of the region utility.

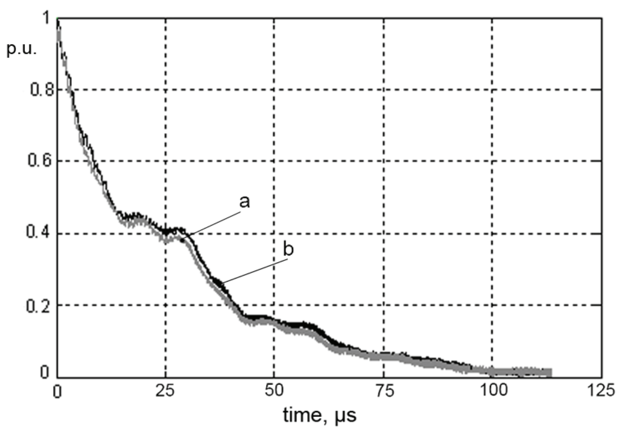

Fig. 5. Calculated wave front (a) and simulated wave front (b)

Manual exploitation of fault location devices based on numerical modelling and recognition of the very fast transients has revealed the main sources of the inaccuracy of the results:

- Inaccurate parameters of the line and inaccurate lengths of branches; especially if error occurs in inlet cable parameters;
- Inaccurate equivalent capacities in the nods of the grid;
- Narrow spectral dispersion of measuring transformers and others.

Disturbances from injured line cause reflections in healthy lines. NSFS uses separation of adaptive parameters subject to real time of recordings. The best adaptation accuracy is obtained for the nearest line branches. The main adaptive parameters are: length of the branches, ground resistance, surge impedances and modal matrixes. The principle of the adaptation of the healthy line parameters is shown in Fig 6.

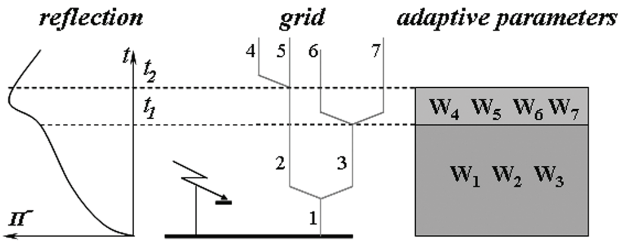

Fig. 6. Adaptation of the healthy line parameters

Nano-second fault spotting technology

The fault point recognition in the network by means of NSFS consists of some successive stages that are realized as the procedures:

- Current and voltage transformers and link circuits to the unit A-D converters somehow spoil transient characteristics of the recordings. The distortions of signal shapes take place in the received voltages and currents. At the first stage these changes and distortions are eliminated in the received data;
- A phase to earth fault current flows to the incident point along the injured line, but in the isolated or compensated network it flows also from all the feeders connected to the substation buses. So, the next calculating stage identifies if the incident point belongs to the feeder that is served by the unit;
- Transient current shape in the feeder depends on the whole network. In addition, any normal commutation in a network changes the grid configuration as well as the current values and its shape. The next stage is connected with evaluation interferences caused by the feeders of the remaining network part;
- The feeder model normally is somehow more or less simplified. Transient parameters of such model as well as the fault incident point have to be searched out only by some optimization procedures. In the NSFS technology, optimizing objective functions are used, which highlight the main features of the parameters and show the configuration of the network grid more clearly;

- Each algorithm step meets various indeterminations, such as all kinds of noises, indefinable simulated network factors and electromagnetic surge parameters, electric initial conditions, etc. Consequently, every algorithm step is accompanied by reliability estimations. This allows to have confidence in final result and to apply some calculated data for adopting algorithm of the unit.

Conclusions

1. The usage of the registrations of the initial processes essentially simplifies digital algorithms meant for fault recognition applications and its good base for development of the new relays which algorithms are based on initial processes analysis.
2. Nanosecond length digital steps, special digital filters and optimizing procedures of net surge parameters are the main spotting keystones in nano-second fault spotting technology applied in the phase to earth fault spotting algorithm.
3. Fast earth fault spot location and faulty line disconnection with network reconfiguration allow to avoid the switching of the line during the earth fault and the development of other faults. Generally, these actions increase the reliability of the network and decrease power outages.

References

1. **Markowska R., Wiater J., Sowa A.** Measurements of Surge Currents and Potentials in a Radio Base Station for Estimation of Lightning Threat // Electronics and Electrical Engineering. – Kaunas: Technologija, 2011. – No. 1(107). – P. 93–98.
2. **Hashmi M., Lehtonen M., Hänninen S.** Modelling and Analysis of Switching Overvoltages Caused by Short Circuits in MV Cables Connected with Overhead Lines // Electronics and Electrical Engineering. – Kaunas: Technologija, 2011. – No. 1(107). – P. 107–110.
3. **Greitans M., Hermanis E., Selivanovs A.** Sensor Based Diagnosis of Three–Phase Power Transmission Lines // Electronics and Electrical Engineering. – Kaunas: Technologija, 2009. – No. 6(94). – P. 23–26.
4. **Czapp S.** Comparison of Residual Current Devices Tripping Characteristics for Selected Residual Current Waveforms // Electronics and Electrical Engineering. – Kaunas: Technologija, 2010. – No. 4(100). – P. 7–10.
5. **Rafajdus P., Bracinik P., Hrabovcova V.** The Current Transformer Parameters Investigation and Simulations // Electronics and Electrical Engineering. – Kaunas: Technologija, 2010. – No. 4(100). – P. 29–32.
6. **Ciufudean C., Filote C., Larionescu A.** New Digraph Models for Diagnosis of Electric Cables // Electronics and Electrical Engineering. – Kaunas: Technologija, 2009. – No. 6(94). – P. 65–68.
7. **Gudžius S., Markevičius L. A., Markevičius L., Morkvėnas A., Miliūnė R.** Elektromagnetinių pereinamųjų procesų modeliavimo izoliuotos neutralės tinkle ypatumai // Elektros ir valdymo technologijos – 2006, Electrical and Control Technologies – 2006: tarptautinės konferencijos pranešimų medžiaga. – Kaunas: Technologija, 2006. – P. 161–166.
8. **Gudžius S., Markevičius L. A., Markevičius L. Morkvėnas A.** The spotting reliability of the transient processes during one phase to ground fault // Proceedings of the XVII International Conference on Electromagnetic Disturbances EMD'2007. – Bialystok: Bialystok Technical University, 2007. – P.183–186.
9. **Siozinys V.** Transmission Line Fault Distance Measurement Based on Time Difference between Travelling Wave Reflection and Refraction // Electronics and Electrical Engineering. – Kaunas: Technologija, 2010. – No. 2(98). – P. 25–28.
10. **Gudžius S., Markevičius L. A., Morkvėnas A.** Recursive method to examine electromagnetic transient processes in cable network // IV Sympozjum, "Metody matematyczne W elektroenergetyce MMwEE'98". – Zakopane, 1998. – P.235–244.
11. **Gudžius S., Markevičius L. A., Morkvėnas A., Markevičius L.** Recognition of Fast Electromagnetic Transients in HV Overhead Lines // Electronics and Electrical Engineering. – Kaunas: Technologija, 2011. – No. 1(107). – P. 103–106.

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Nowadays it is thought that distribution power networks have the ability to isolate damaged power network place by making optimal links, to identify the fault character, to recognize the character of transients, to establish the fault cause and estimate the state of electrical equipment. For such an objective, fast identification of the earth fault and its place location is a very important problem which requires reliable solutions. The paper describes the new algorithm of earth fault detection and location which is based on the analysis of the initial processes of the fault and its keystone elements. The earth fault detection and location algorithm has been implemented in distribution network state identification terminals. Ill. 6, bibl. 11 (in English; abstracts in English and Lithuanian).

S. Gudžius, U. Karaliūtė, L. A. Markevičius, A. Morkvėnas, R. Miliūnė. Įžemėjimo vietos nustatymas pagal pirmines charakteristikas // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2011. – Nr. 5(111). – P. 55–58.

Gerinant skirstomųjų elektros tinklų darbo kokybę bei siekiant ekonomiškumo, pastebimą efektą galima pasiekti daugiau dėmesio skiriant elektros tinklų modernizavimui ir automatizavimui. Elektros tinkle įvykus gedimui intelektualiai automatizuota valdymo sistema per kiek galima trumpesnį laiką atlieka veiksmus gedimui atpažinti, jo vietai nustatyti ir taip pakeisti elektros tinklo struktūrai, kad tik minimalus elektros vartotojų skaičius liktų neprijungtas prie tinklo, o elektros priežiūros tarnybos gautų informaciją apie gedimo pobūdį, vietą ir mastą. Todėl labai svarbu greitai ir patikimai nustatyti įžemėjimo vietą. Straipsnyje aprašomas naujas įžemėjusios linijos ir įžemėjimo vietos nustatymo algoritmas, pagrįstas greitų pradinių procesų analize. Šis algoritmas buvo panaudotas elektros tinklo būklės nustatymo terminaluose. Il. 6, bibl. 11 (anglų kalba; santraukos anglų ir lietuvių k.).