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УДК 621.311

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FUZZY-LOGIC ALGORITHM FOR DETECTION OF INTERMITTENT EARTH FAULTS

У разі коротких замикань, які особливо важко визначити, ефективність роботи захистів можна покращити використанням нестійких замикань на землю. Нестійкі замикання в розподільних мережах середньої напруги часто не реєструються звичайними захистами від замикань на землю, і як наслідок, не можуть бути усунені. Під час таких замикань генеруються нестаціонарні періодичні сигнали вимірювання. Згладжування сигналу, наприклад, усередненням її в межах відповідного інтервалу, призводить до зниження величини нижче від значення уставки спрацювання і традиційна бінарна логіка (так/ні – замикання/відсутність замикання) для реєстрації замикання не є надійною. Нечітка логіка працює тут краще. В роботі запропоновано захист на основі нечіткої логіки.

In the case of faults which are especially ‘difficult’ to detect, the effectiveness of the operation of protections can be improved using fuzzy logic. It refers mainly to the intermittent earth faults. The intermittent faults in the MV distribution grids are often unnoticed by the conventional earth fault protections and, consequently, are not eliminated. In such faults, the periodically non-stationary measuring signals are generated. By smoothing the waveform, for example by averaging it within an appropriate interval, the criterion value falls below the start-up value and the fault discrimination using traditional binary logic (true/false – fault/ lack of fault) is not ensured. The fuzzy logic fits here better. In the work, the protection with fuzzy decision system is proposed.

Introduction. Effectiveness of elimination of disturbances by protections depends strongly on propriety of distinction between the normal operating conditions and the emergency conditions like a fault. It is lied with description of the position of the decision vector’s trajectory within one of two regions corresponding to these conditions. In this simple two-value (binary) logic, the position of decision vector must be unambiguously assigned to the one of two possible regions: the region of the object’s normal operation and the faulty operation’s one.

The binary logic adequate to the standard decision characteristics may not be straightforwardly applied when a third decision region (i.e. uncertainty region) occurs [5]; it could lead to either to some unneeded operations or the missing operations (non-operations needed) [2–4], the latter being especially dangerous. The uncertainty region, if any, decreases often as the transient decays. In such cases, the introduction of time delays enabling to 'wait through' the fault transient is sufficient to limit the number of incorrect operations of protections. Such approach is not allowed for faults which must be eliminated quickly or is inefficient if the uncertainty region occurs during the fault duration. In such cases, the fuzzy sets' theory can provide a good tool for synthesis of the protective algorithms. In the paper, the disturbances are discussed during which the signals are hardly deformed by the high order harmonics and, consequently, the criterion values of protections found referring to these signals become ambiguous. The single-phase intermittent earth faults in the grid with small earth faults current have been considered as representative one. This type of faults is relatively frequent and its detection makes troubles [4]. A new protective algorithm using the fuzzy logic-based detection system is presented.

Measuring signals. For analysis of faults with highly deformed measuring signals, two types of the intermittent earth faults recorded in the true grid been chosen. In Fig.1 the phase voltages during non-detected intermittent fault with an 8 sec decay is shown. In this figure, the mechanism of formation of intermittent earth faults can be tracked. After each individual fault's decay (for example, after the arc snuff out at the fault location), the restoring voltage of damaged phase reaches the critical value of the arc restrike (point A or B – Fig.1) and the arc extinguishes in some periods; then the process is repeated periodically with relatively high cadence.

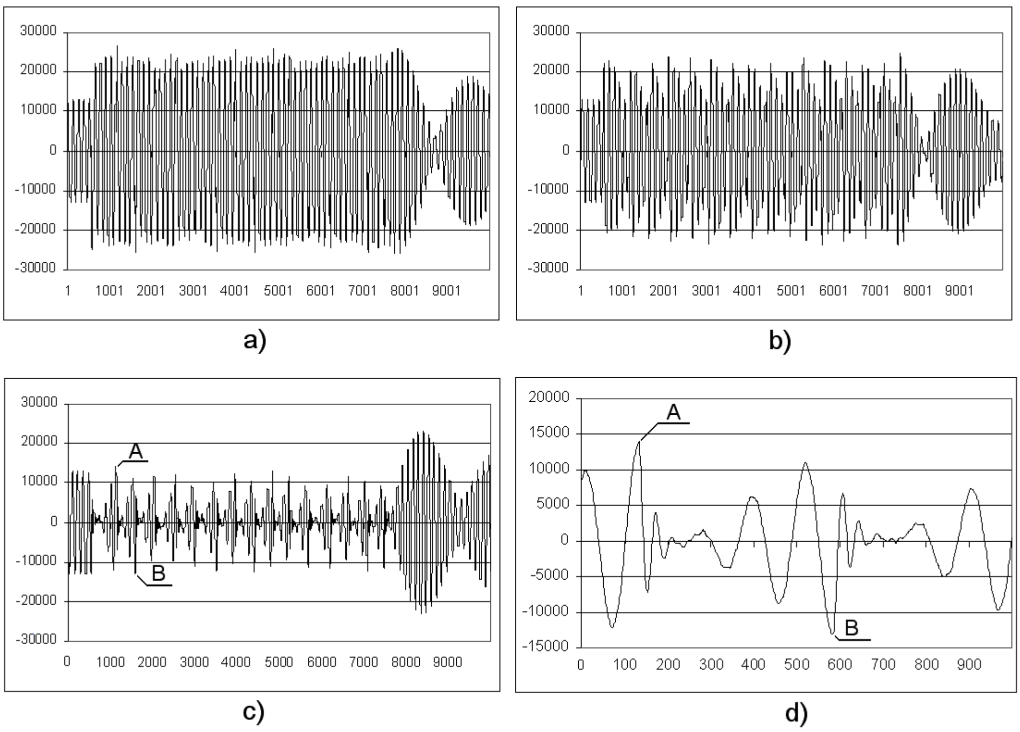

Fig. 1.Voltage waveforms (UL1 – a, UL2 – b, UL3 – c) during intermittent earth fault which decays spontaneously after. 8 s; zoom of section of the phase voltage UL3 – d

Typical earth fault protections in the Polish compensated distribution grids can operate basing on the directional or directionless admittance criterion (conductance criterion). To implement such protections, the signals which are the linear combinations of the zero voltage component U_0 and zero current component I_0 in the individual lines are used. For instance, the signals described by formulas (1) are used in the conductance criterion:

$$S_{1x} = \left| mU_{0x} + nI_{0y} \right|$$
$$S_{2x} = \left| mU_{0x} - nI_{0x} \right| \tag{1}$$

where x – sample's number, m – weight coefficient for the voltage samples, n – weight coefficient for the current samples.

The decision on the operation of the protections can be taken referring to the comparison of the specially filtered values of the start-up signals with the setting values. Denoting the start-up values by *Pv* (pick-up value) and the setting values by *Sv*, the start-up conditions for the conductance criterion can be expressed by the following relationship:

$$\left| Pv(S_{1x}) - Pv(S_{2x}) \right| F Sv(U_{0x}) \tag{2}$$

However, this classic approach can be ineffective as to the intermittent earth fault. Such a case is shown in Fig. 2 in which the waveforms of the instant conductance values measured by the protection during faults are presented.

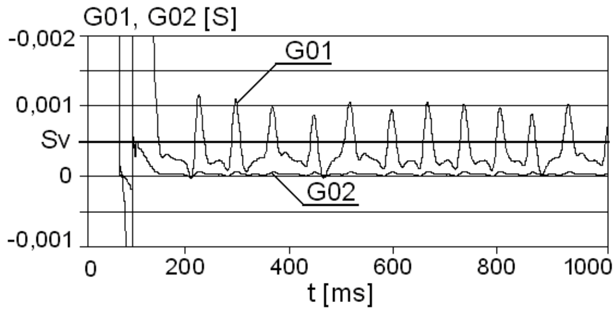

Fig. 2. Instantaneous value of conductance of the damaged (G01) and healthy (G02) lines; Sv – setting value of protection

During the intermittent faults, there are only some instants when the value of the damaged line conductance exceeds the start-up value (*Sv*); in intervals between consecutive faults, the value is close to the healthy line conductance; thus, a typical uncertaity region has occured. In result, the proper detection and localization of the fault can become impossible. A degree of the measuring signals deformation is so high that the filtration of useful signals does not improve the situation sufficiently.

The non-detected intermittent fault can turn into more dangerous inter-phase fault. The phase voltage waveform during entire complex disturbance is presented in Fig. 3. Three characteristic sections have been separated from the entire distrurbance process:

- single-phase intermittent fault of the phase L1 (sector A),
- single-phase permanent fault of the phase L1 (sector B),
- two-phase earth fault of the phases UL1 – UL.2 (sector C).

The fault being a single-phase intermittent at the beginning turns into the single-phase permanent fault and, finally, becomes the two-phase one. Not but the latter has been 'perceived' by the protective automatic and then eliminated. The total fault duration time is of about 5 seconds.

In Fig. 4, the zero components of the network voltage and current in the damaged line are shown.

However, the modern microprocessor technics offer wide variety of opportunities to create more nad more sophisticated algorithms mining necessary information hidden within the measuring signals [1]. Below, the algorithms referring to the logic other then that adapted in the clsassic admittance criterions are presented.

Fuzzy logic-based algorithm. Before the fuzzy-logic-based protective algoritm is applied, the measuring signals shown in Fig. 1 are to be formed properly.

To discriminate the damaged line, the characteristic process' marks related to the intermittent faults are used. To emphasize these marks, the measuring signals are pre-processed by computing the following criterion value:

$$C_{ri} = \int_0^{tf} \frac{\mathrm{sgn}[k_1 \cdot I_{0i}]}{\mathrm{sgn}[k_2 \cdot U_0]} dt \qquad (3)$$

The value is proportional to the phase angle of the zero line admittance. The integration interval *tf* as well as the integration method are arbitrary.

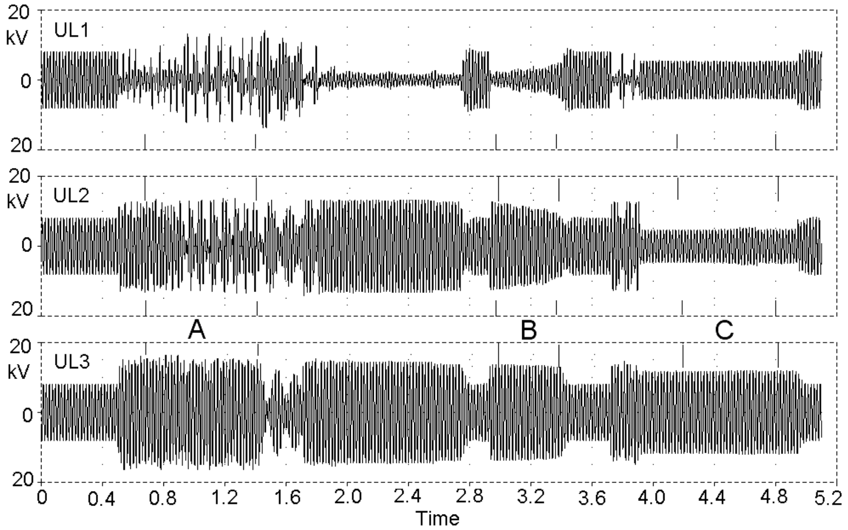

Fig. 3. Voltage waveforms during the intermittent earth fault which turns into the two-phase fault after 3.8 seconds

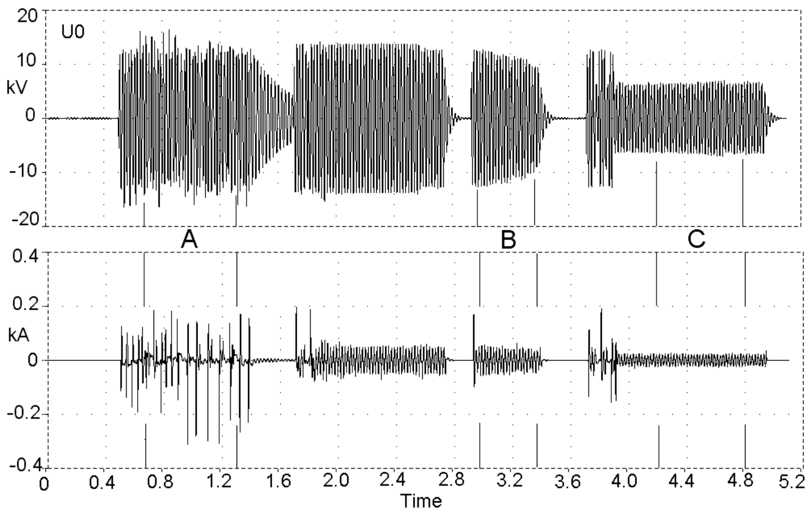

Fig. 4. Zero voltage component (U0) and zero current component (I01) in damaged line

For the real-time algorithms, the filtration process with the zero-order Walsh filter is recommended. Regarding the allowable time delay (some seconds) for this protection type, there are no special restrictions as to the measuring window length. The recommended length of the window, (*tf*), may fall into 20–60 milisec. The integrand (3) takes values ± 1.

An example of the signal processing path structure is shown in Fig. 5. The places the signals presented in figures 6 and 7 come from are denoted by numbers 1, 2, 3 and 4. The zero components of voltages and currents for the individual lines (waveforms separated A, B and C section are shown in Fig. 6) are applied to the measuring path input (point 1).

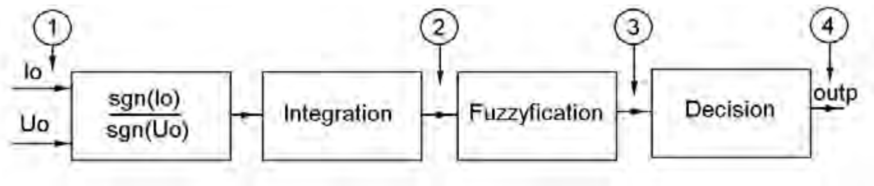

Fig. 5. Structure of Signal processing path

After having processed the input signals according to the procedure (3), the criterion value C_{ri} *is* obtained (point 2 – Fig. 5). On the criterion value *Cri* obtained that way the fuzzification process is carried out (point 3 – Fig. 5) and the assessment is made to state to what extent the fuzzed criterion value ‘belongs’ to the emergency conditions’ region limited by the fuzzy setting value (FSv). From the fuzzification process, the affiliation coefficient μ is obtained. The run of the affiliation coefficient forms a base for the defuzzification resulting in the decision – the binary signal (BS) is transmitted to the final control element of the system protection.

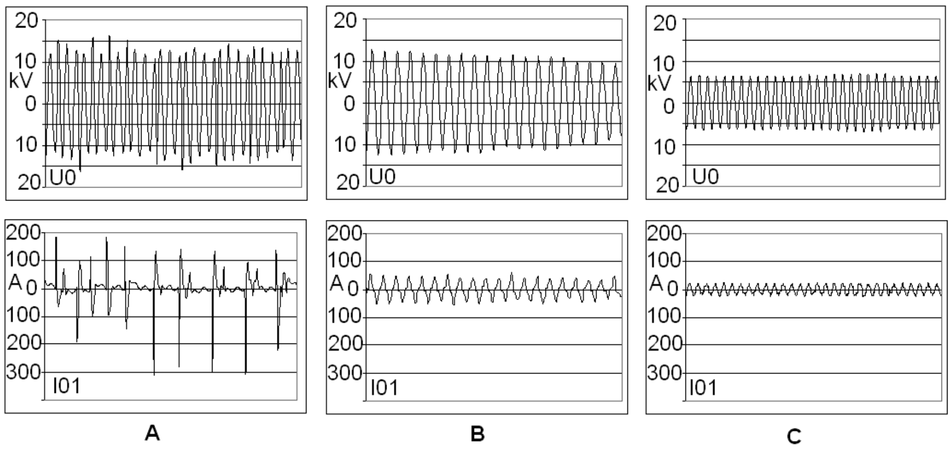

Fig. 6. Voltage and current zero components for separated A, B *and* C *sectors of complex disturbance; Fig. 4, p. 1*

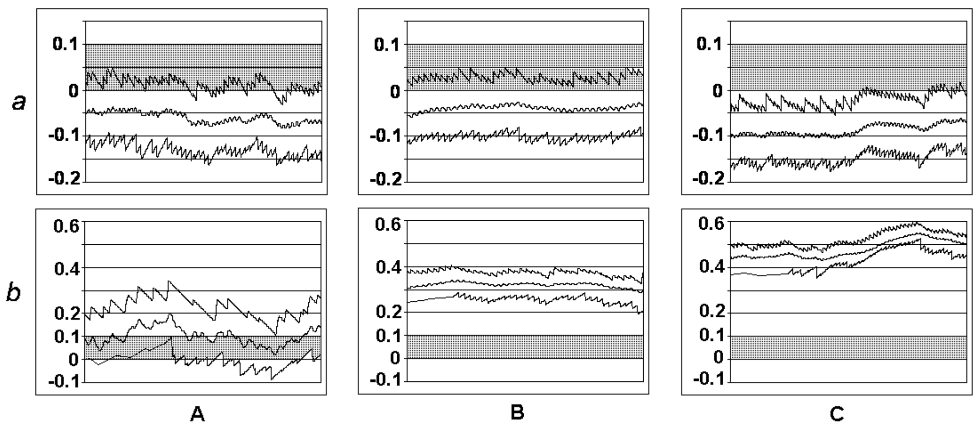

Fig. 7. Measuring signal time waveforms at the points 2 of measuring path (seeFig. 5) for separated A, B *and* C *sectors; a – healthy lines, b – damaged line*

The implemented method of defuzzyfication is capable to:

i – identify a healthy line (μ = 0, BS = 0 for every presented case – fig.8. rows a1 and a2, sectors A, B and C),

ii – detect the line with permanent fault (μ = 1 fig.8, rows b1 and b2, sectors B and C), iii – identify the line with intermittent earth fault (μ overcomes the starting limit for majority of samples – fig.8, rows b1 and b2, sector A).

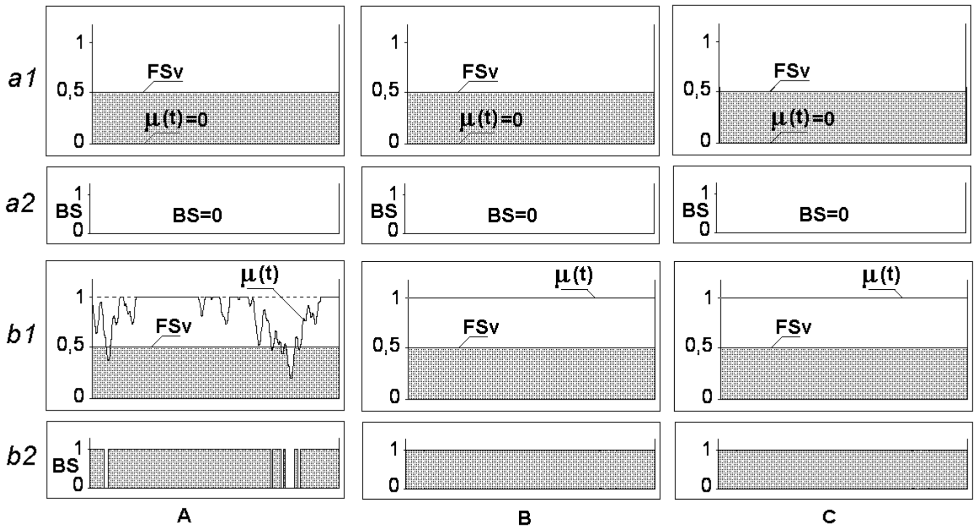

Fig. 8. Affiliation coefficient μ *(points 3 of measuring path – Fig. 5) and the binary signal* BS *(points 4 of measuring path – Fig. 5) for separated* A, B *and* C *sector; a1, a2 – healthy lines; b1, b2 – damaged line*

Final remarks. The reported cases of intermittent earth faults and the accompanying basic measuring signals indicate that the detection of these faults as well as the damaged line discrimination can be difficult for conventional earth fault protections.

The feature of the intermittent earth faults is the periodically repeated transient leading to the periodical changes in the measuring signals. In the cadence of the changes, the criterion values of protections decrease below the start-up protective values; in result, the distinction between the damaged and healthy lines makes troubles and can lead to missing operation or erroneous interpretation of the disturbance by the existing protections. A number of the faults which can not be indicated precisely decays spontaneously and is, in general, not considered in the statistical data concerning the unreliability of the MV grids. Another risk related to the missing detection of the arc intermittent fault is that, due to the earth fault over-voltages, the latter turns into the inter-phase fault resulting mostly in the indelible damage of insulation.

In such cases, the implementation of unconventional criterions for the fault detection purpose can be expedient. One solution is to apply the fuzzy logic –based decision algorithm for the damaged line discrimination regarding the ambiguity (fuzziness) of measuring signals during the disturbance. The true technical cases have been discussed, representative to the entire category of faults. In effect, an important improvement in the operation selectivity of protections has been achieved. Apart from the simulation tests [6], the true measuring signals have been applied in the proposed solution and, consequently, the true operating conditions of the MV grid have been considered. Thus, the approach is valuable for application. .

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УДК 621.311

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MODELING OF OPERATING CONDITIONS OF THE MEDIUM VOLTAGE NETWORK EARTH FAULT PROTECTION

Викладено результати комп'ютерного симулювання режимів роботи захисту від мережі середньої напруги. Швидка оцінка цих режимів може бути метою обчислювальної системи KSAZ, розробленої інститутом електроенергетики Познанської політехніки. Результати досліджень можна показати різними способами. У цій статті результати подано у комплексній площині.

In this paper, the computer simulation results of operating conditions of the medium voltage (MV) network earth-fault protection are presented. A fast on-line assessment of these conditions can be aided by the computing system KSAZ (Protection Analysis Computer System) developed in the Institute of Electric Power Engineering, Poznań University of Technology. The results of research can be shown in a few ways. In the paper the results on the complex plane are presented.

Introduction. A large quantity of high-resistance faults in overhead lines, different ways of neutral point grounding in rural MV networks, low level of decisive signals, are only few reasons which caused the development of new earth fault protections [1, 2, 3]. In Polish Elecrical Power Distributions, relays based on admittance criteria turned out to be most effective ones [4]. The software package KSAZ [5,6] became the tool enabling the appropriate choice and correct settings of the earth fault protections. In Fig. 1. the structure of the KSAZ program is shown.

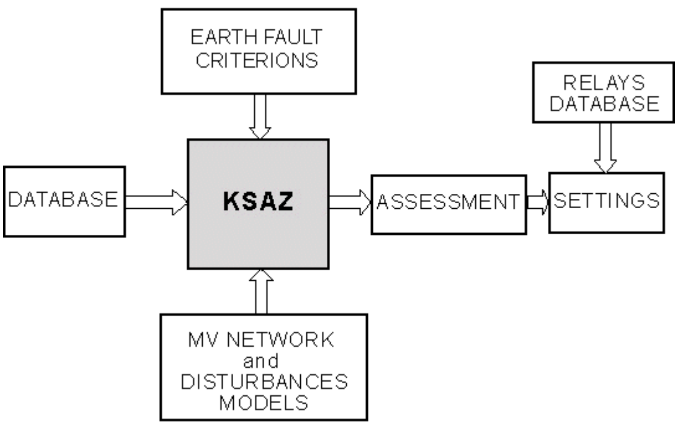

Fig. 1. Block diagram of the system KSAZ

In order to analyse the phenomena accompanying the earth-faults MV network model and the disturbances model were created. The scheme of the compensated network is shown in Fig. 2. Among others, earth-fault capacitances (C_0) and conductances (G_0), fault point resistance (R_F), zero-sequence