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Measuring Device for Determination Fault Location in Transmission Lines Based on Stochastic Adding A/D Conversion

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Abstract: This work describes a device, locator of breaks in transmission networks, based on the Stochastic Additional A/D converter. An algorithm has been used for detection does the complete analysis of circuits within the break and locates the location of the break BEFORE the protection reacts. The time needed for this is 40-80 ms. The algorithm for calculation requires data about the type of the network, characteristic values of its parameters and values of some harmonics of signals of the voltage and electricity that are measured. They are ON-LINE extracted at every 10 ms. The stochastic additional A/D converter (SAADK) is used for the extraction of these harmonics. Simulations of the work of the device have been done on generated readings of electricity and voltage, and on real images of the break. Special attention has been paid to the analysis of accuracy of the work of the device. A theoretical error is also given in the values realized from simulations.

Keywords: Measurement, fault locator, stochastic conversion, transmission lines, simulation.

1 Introduction

One of the most vulnerable segments of the electro-energetic systems are transmission lines or above-ground power lines within a sub-system of transmission of electric power. They are the most exposed to the atmospheric

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influences; hence there are many different types of breaks. Generally speaking, these breaks can be divided into two groups: temporary and permanent. The most usual are the breaks of the temporary type (around 90%), caused by the atmospheric discharges, atmospheric phenomena such as fog or dew or increased air pollution. Therefore, most breaks have an electric arch. Both kinds of breaks cause reactions of protection switches, which switch off the voltage at the section stricken by the break. Knowledge of the type and the location of the break is important for two reasons:

1. In order to isolate the break and restore the network and
2. In cases of a temporary break, to enable the team to access the location of the break and remove it in the shortest possible time. The detection of the electricity arch is very important if one wants to determine the type of the break, that is, to decide about the way of subsequent putting of voltage into the line.

Algorithm [1], due to considerable demands for computing resources in the support processor, has been selected for the implementation of a recently developed measuring method called Stochastic Additional A/D Conversion (SAADK) [2]. Within the work, it is shown how the algorithm [1] and the SAADK [2] method can efficiently detect the type and the location of the break.

2 Algorithm for Detection of the Location of the Break

Within the work, an algorithm will be presented, which enables detection of the most widespread monopolar breaks and how it determines the location of the break on the basis of that. An important advantage of the algorithm, in comparison to the others is, as previously said, that the detection of the type and the location of the break is done BEFORE the protection reacts, that is, during the time when there is voltage in the line as well as the signal of the break. This time lasts 24 periods and is sufficient for GSAADK-2G (a generalized stochastic A/D converter with two generators of random numbers) [3] to calculate the needed harmonics (the first and the third). The electricity arch itself is very non-linear and is alike the current of the phase. Because of such a form, the electricity arch generates higher harmonics of voltage and electricity, which are spread in the network. For the development of the model, the adopted form of the arch is shown in Figure 1. The form of the electricity arch from Figure 1. can be presented by Fourier's polynomial, which contains only odd sinusoidal harmonics, and cosinus elements may be neglected, as presented in (1):

$$u_a\left(t\right) = \sum_{h=1}^{\infty} k_h U_a \sin\left(h\omega t\right) \tag{1}$$

where U_a is voltage of the electricity arch, h - 1,2,3 - order of harmonic; k_h - coefficient of the k of the harmonics. We may write that $U_{ah} = k_h U_a$, where U_{ah} is the amplitude of the h harmonic.

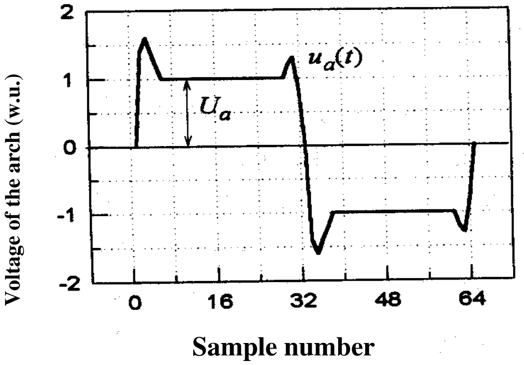

Fig. 1. Ondular form of voltage of the arch.

The researches [1] have shown that the harmonics 1 and 3 are stable through time, and that harmonics higher than them are unstable and therefore are not used. For the calculation of the harmonics, one must start from the "π" of the equivalent scheme of the circuit, Figure 2.

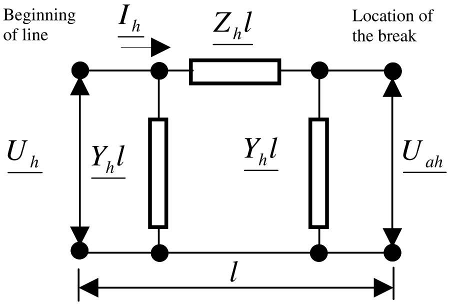

Fig. 2. Equivalent circuit of a broken line.

The values of the parameters of impedance and admittance are known in advance for each circuit. From the general theory, it is known that the method of symmetrical components [1] can be applied on such a circuit. After the derivation [1] the result that we get is that for lines of up to 150 km with protection strings, the distance of the break l is calculated from:

$$l = \frac{\underline{U_1} - \underline{K}\underline{U_3}}{\underline{Z_1}\left(\underline{I_1} + \underline{K_1}\underline{I_{10}}\right) - \underline{K}\underline{Z_3}\left(\underline{I_3} + \underline{K_3}\underline{I_{30}}\right)} \tag{2}$$

where $\underline{K_1} = \dfrac{\underline{Z_{10}} - \underline{Z_1}}{\underline{Z_3}}$, $\underline{K_3} = \dfrac{\underline{Z_{30}} - \underline{Z_3}}{\underline{Z_3}}$, $\underline{K} = \dfrac{\underline{k_1}}{\underline{k_3}} = \dfrac{\underline{k_1}\angle\varphi}{\underline{k_3}\angle 3\varphi}$.

Now that we know the distance of the break l.

Even though this model applies to mono-polar breaks, it may be applied to tri-polar and bi-polar short-circuits by equalizing the zero values of voltage and electricity with zero. The model also applies to a case of two-side influx into the line, however in that case the computing error increases [1]. But how can the 1st and 3rd harmonics be extrapolated into $2 \div 3$ periods?

3 Extrapolation of the Needed Harmonics through GSAADK

This work shows that it can be accomplished through application of a modified GSAADK-2G [2] whose basic block scheme is presented in Figure 3.

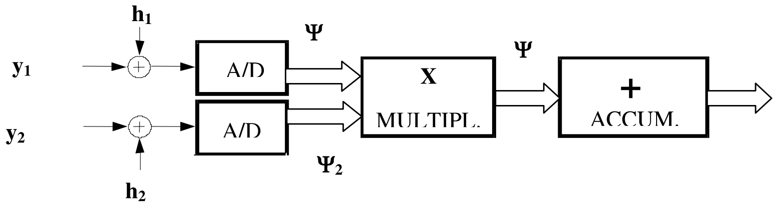

Fig. 3. Generalised stochastic device for power measuring.

$y_1 = f_1(t)$ and $y_2 = f_2(t)$ entry signals are integrable functions, h_1 and h_2 are generators of random noise, inner-independent and meeting conditions:

$$0 \leq |h_i| \leq \frac{a}{2}, \text{ Widrow's condition} \tag{3}$$

$$p(h_1) = \frac{1}{a}, \quad (i = 1, 2) \tag{4}$$

Ψ_1 and Ψ_2 are results of A/D conversion. The output from the accumulator after a time T is:

$$\overline{\Psi} = \frac{1}{T}\int_{0}^{T} f_1(t) \cdot f_2(t)\, dt \approx \frac{1}{N}\sum_{j=1}^{N} \Psi_j \tag{5}$$

$$\Psi = \Psi_1 \cdot \Psi_2 \tag{6}$$

where N is the number of samples in the time T.

If the harmonics are measured, for $y_2 = f_2(t)$ we take that it is a simple-periodic function [3], hence Ψ_2 can be generated from a memory block MEM as shown in Figure 4.

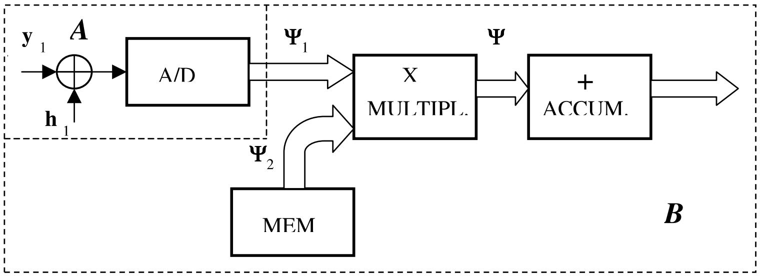

Fig. 4. Generalised stochastic device for power measuring.

In Figure 4 it can be seen that there are two distinctly separated parts: the part marked "A", which is analog-digital, and the part marked "B", which is strictly digital. With this simplified hardware, we can simultaneously measure a few coefficients of the Fourier's polynomial (the first and the third sinus) in Figure 5. The output from the accumulator in a time T is

$$\overline{\Psi} = \frac{1}{T}\int_{0}^{T} f_1(t)\, R\cos(k\omega_0 t)\, dt = \frac{R \cdot b_k}{2} \tag{7}$$

which is also a general formula for calculation of Fourier's coefficients. If the principal is paralleled for two harmonics than we get the image from Figure 5. Moreover, the resolution of the basic function from the MEM block does not have to be the same as the resolution of the A/D converter, and it can be significantly higher. This is the basis for realization of the DFT processor.

A theoretical error in measurements of the harmonic through GSAADK, is calculated for the mentioned case, when $a_1 \gg a_2$, where a_1 is a quantum

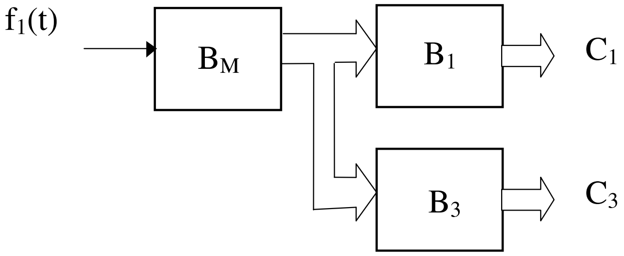

Fig. 5. Generalised stochastic device for power measuring.

of the flash A/D converter, and a_2 is the quantum of the generalized basic function from the MEM block.

First, we calculate the value of the variance:

$$\sigma_{\bar{e}}^2 \le \frac{a_1^2 \frac{1}{T} \int\limits_0^T f_2^2\,(t)\,dt}{4N} \tag{8}$$

For the calculation of the 1st and the 3rd sinus coefficient the basic function $f(t)$ has the values, successively [4]:

$$f_2\,(t) = \begin{cases} R \sin \omega t \\ R \sin 3\omega t \end{cases} \tag{9}$$

The value of a relative error is

$$\Gamma = \frac{\sigma_{\bar{e}}}{\overline{\Psi}} \tag{10}$$

Since

$$\overline{\Psi} = \frac{b_1 R}{2} \tag{11}$$

we get

$$\Gamma = \frac{a_1}{\sqrt{2N} \cdot b_1} \tag{12}$$

The value of $a_1 = \dfrac{R}{36}$ (6-bit A/D converter), hence:

$$\Gamma = \frac{R}{\sqrt{2N} \cdot 31 \cdot b_1} \tag{13}$$

where N is the number of samples in time T; b_1 - is a sinus coefficient of the first harmonic; Γ is the theoretical value of a relative error in the measuring of the harmonic.

On the basis of (12), it can be seen that the upper boundary of an absolute error in the measuring of a harmonic is defined only by the resolution of the applied A/D converter, the size of the harmonic and the number of measuring in the sample (the size of the table), and that it does not depend on the form of the entering function.

It ought to be emphasized that for the assessment of the error it is supposed that the A/D converter is a 6-bit one, and that the basic function is defined with $N = 10^6$ of 10-bit measuring in the memory. The result Ψ, is $6 + 10 = 16$-bit, so the multiplier can be a simple look-up table in a 64 kB memory chip, and 16-bit results can simply be accumulated in appropriate PLD accumulators.

All calculations of errors were for idealized values of elements in the scheme, which is not the case in practice. This is particularly important for 6-bit flash A/D converters. The comparators contained therein, all 64 of them, have an offset, which must be taken into account [3]. The impact of the offset is equivalent to adding a small non-linear entry function onto the entry measure signal y_1. This function is marked $\varphi(y_1)$. It is liable to:

$$|\varphi(y_1)| \leq \varepsilon \ll R \tag{14}$$

After the derivation, we get that the average value of the real output from the multipliers $\overline{\Psi}_r$ is [2]:

$$\overline{\Psi}_r = \frac{1}{T}\int_0^T y_1 \cdot f_2(t)\,dt + \frac{1}{T}\int_0^T \varphi(y_1) \cdot f_2(t)\,dt = \overline{\Psi} + e_d \tag{15}$$

The value e_d is a deterministic error due to the offset, hence [4]

$$\Gamma_d = \frac{|e_d|}{|\overline{\Psi}|} \leq \frac{2\varepsilon R}{\pi} \cdot \frac{1}{R^2/2} = \frac{4}{\pi} \cdot \frac{\varepsilon}{R} \tag{16}$$

For real values, if $\varepsilon = 1$ mV and $R = 5$ V is:

$$\Gamma_d \leq \frac{4}{\pi} \cdot \frac{1}{5} \cdot 10^{-3} = \frac{4}{15.7} \cdot 10^{-3} \approx 0,025\,\% \tag{17}$$

Obviously, the offsets of the comparators in the flash A/D converter cause considerable limitation of accuracy of the measuring of the harmonic. As it takes three measuring of voltage and three of electricity for the calculation of the model ([1], chapter 3), as well as extrapolation of the 1^{st} and the 3^{rd} harmonics, the feature of the hardware must be modified into the form in Figure 6.

4 Hardware Proposal for the Device

From the aforesaid, it can be seen that the entry values for the realization of the model [1], the values of electricities and the voltage are of a few periods after the break. The values whose harmonics are measured in a tri-phase system are phased voltages and electricities, interim phased voltages and differences between phased electricities, the usage of these values depends on the type of the break. The number of entry values is smaller than the number of output ones, that is, for one entry value a few values of the harmonic are sought. In our case, harmonics of nine entry values are needed. These are phased (3), interim phased (3) voltages and phased currents (3). The difference between phased electricities is calculated at the end in a microprocessor. This takes changes in the configuration from Figure 5 in the following way (Figure 6). Where the blocks are in order: MUX - multiplex, FADC - flash A/D converter, X - multiplier, MEM - memory, ACCUM - accumulator. The generalization from the MEM block is done in

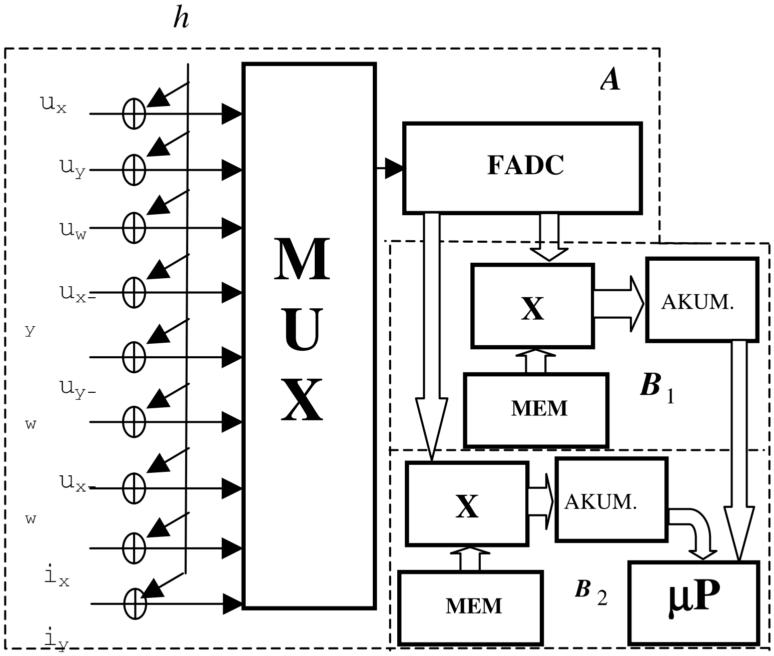

Fig. 6. Block scheme of a part of the hardware of the device for calculation of needed harmonics.

10-bit, and FADC is a 6-bit one. It can be seen that

$$a_1 = \frac{R}{31}, \tag{18}$$

and that

$$a_2 = \frac{R}{511}, \tag{19}$$

where R is a full range of entering values GSAADK-2G.

So, $a_1 \gg a_2$. This means that the equations presented for GSAADK-2G are also applicable here, as well as pertinent errors.

How does the hardware device from Figure 6. behave in reality? Its simulations and results are given in the following chapter.

5 Simulations

The purpose of this work is to prove the possibility and accuracy of detection of the location and the type of the break through utilization of GSAADK. First, we must have readings of the voltage and electricity at the point of the relay installation. The voltage of the break (arch), showing at the break is to be "embedded" into these signals. A monopolar break with an electricity arch was selected for the experiment, since it is very easy to derive the others from it, and the equation ([2]) was applied for the calculation of the distance.

The simulation program for monopolar short circuit was used for getting accurate simulations with necessary corrections.

Sub-transient, transient and stable regimes of the break were simulated. The number of simulated samples per a period was 1800.

Simulations of this type were needed in order to examine applicability and accuracy of the algorithm [1]. The simulations of monopolar short circuit were written in FORTRAN. A two-side voltage sourced line was simulated, with a distance to the sources of 100 km. The break was in one "a" phase.

The signals presented in Figures 7 and 8 were obtained on basis of these data, and with the distance to the break set.

Figure 7 shows the image of the voltage at the location of installation of a protection relay, with a break at 10 km. The break begins at 60 ms, on the phase "a". The value of one r.u. (relative unit) for the voltage in Figure 7 is 127 kV (the line is 220 kV). The referent voltage for determination of the phase for calculation of l (distance to the break) is the voltage of "a" phase.

In Figure 8, current is shown in a network at the location of installation of the relay for the case of a monopolar short circuit, for a break at 10 km.

The value of 1 r.u. for the electricity in the figure is: r.u. for the basic voltage divided by the basic impedance or in absolute units.

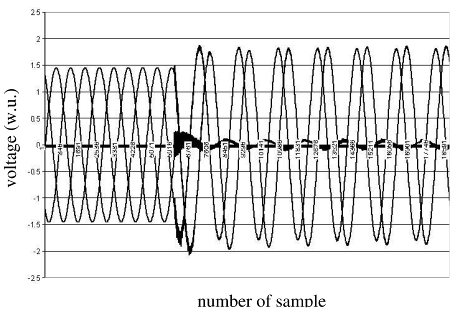

Fig. 7. Voltage on side A (break at 10 km).

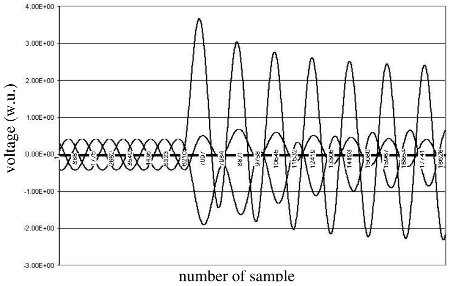

Fig. 8. The value of current on side A (break at 10 km).

$$I_b = \frac{127\,\mathrm{kV}}{360\,\Omega} = 352.7\,A \tag{20}$$

From these simulated images, GSAADK (its simulation program) did a successive determination of sinus Fourier's coefficients b_1 and b_3 at every 10 ms. It has already been said, that the break given in the images begins at the end of the third period (60 ms) of the voltage of "a" phase. The values is calculated at every 10 ms. The results of that calculation are given in Table 1 and in the Figure 9.

Table 1. Calculated values for l, break at 10 km.

Sample No.	Time t (ms)	Distance l (km)
1	10	2199
2	20	2199
3	30	166.9
4	40	55.38
5	50	109.9
6	60	12.135
7	70	10.45
8	80	10.2415

Similarly, a calculation was done for the break point and for cases of breaks at 90 and 50 km, as shown in the Figures 10 and 11 Out of the values from Figures 9, 10 and 11 it can be seen that the computing error of the distance l to the break in these cases is successively 1 %, 1.2 % and 2.4 %.

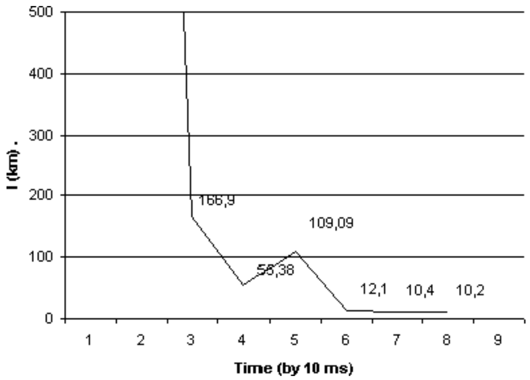

Fig. 9. Diagram of calculated values of distance to the break spot in case of a break at 10 km.

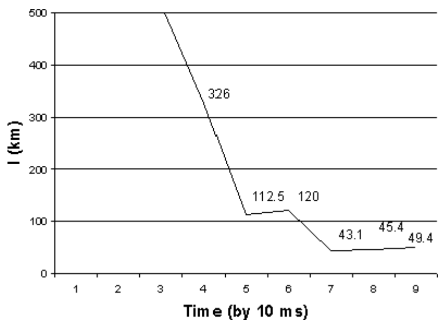

Fig. 10. Diagram of calculated values of distance to the break spot in case of a break at 50 km.

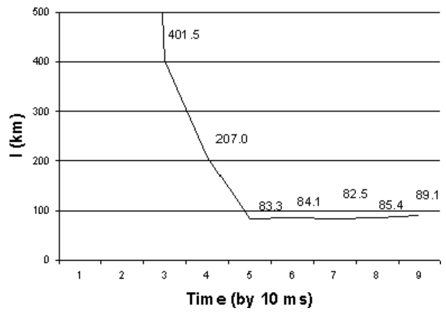

Fig. 11. Diagram of calculated values of distance to the break spot in case of a break at 90 km.

6 Conclusion

For determination of the location and the type of the break [1], on the basis of the first and the third harmonic of the voltage and electricity of a line stricken by a break, derived from GSAADK, it took signals of the voltage and electricity at the relay installation, but those which comprise a break of a monopolar short circuit type with an electric arch. Through a simulation, such forms of electricity and voltage were obtained (Figures 7 and 8 for a break at 10 km). The break in the images generated by the simulation program (monopolar short circuit), begins after three periods of voltage on phase "a", which is also selected to be the referent one. Also, on this phase, a short circuit was simulated. The number of samples in a period is 1800.

On the basis of these simulations of voltages and electricity, the location of the break was determined l, for cases of breaks at 10, 50 and 90 km. The values of l were calculated at every 10 ms for all three cases, so the results are obtained for these values for the periods before, during the break, and for a stable break. For the case of a break at 10 km, the Table 1. shows it in a numeric form, while the Figure 9 - the distance to the break, has it graphically. The Figures 10 and 11 show the cases of breaks at 50 and 90 km. The values of sinus harmonics b and b are calculated via the GSAADK model at every 10 ms for all the values, but during one period.

From Figures 9, 10 and 11 it can be seen that the calculated value for differs from those set in the simulations [1]. These deviations are between $2 \div 3$ %.

These samples have already been listed. A small numbers of measurings in a period (here it is 1800 for JKPS) of variations of the length of a period in the measured signal of a non-linear sinusoid etc.

Simulation models for GSAADK are written in three different program packages in order to avoid possible errors in the model itself. The obtained accuracy is considerably below the theoretical [4] one, because the application conditions are also far from theoretical ones. It turned out, that by comparison of the error of harmonics b_1 and b_3 and the error of the break location l, these errors were fairly similar, hence the impression was that the algorithm [1] didn't introduce an error. This fact is worthy of further elaboration.

Therefore, GSAADK can serve for determination of the distance to the break, with accuracy between 2 and 3 %.

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