On the Errors of Impedance Measurement Relays used in Distance Protections for Electrical Lines

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Abstract: In this paper, some considerations concerning the errors induced by impedance measuring elements in case of distance protection are presented. The real position form of the actuating characteristic is determined and compared to the ideal situation defined in case of using low sensitivity threshold elements.

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1 Introduction

The shape design of the actuating characteristic of the impedance measuring elements requires computations in which current $\underline{I}$ and voltage $\underline{U}$ in the fault loop are implied. In the specific case of protections based on absolute values comparison the principle scheme is presented in Fig. 1.

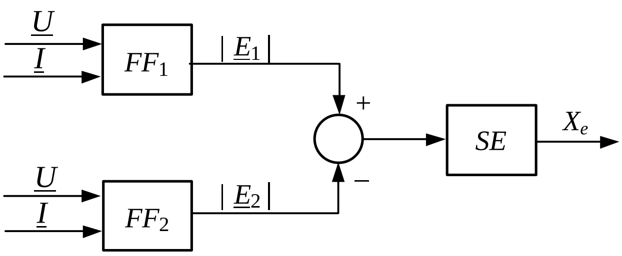

Fig. 1. The principle protection scheme based on absolute values comparison

It was denoted as FF_1 and FF_2 the function generators, and SE the sensible element. In general, the values $|\underline{E}_1|$ and $|\underline{E}_2|$ are described by:

$$|\underline{E}_1| = k_n\,|\underline{K}_{1U}\underline{U} + \underline{K}_{1I}\underline{I}|^n \tag{1}$$

$$|\underline{E}_2| = k_n\,|\underline{K}_{2U}\underline{U} + \underline{K}_{2I}\underline{I}|^n \tag{2}$$

where: $\underline{K}_{1U}$, $\underline{K}_{2U}$, $\underline{K}_{1I}$, $\underline{K}_{2I}$, depend on the type and connection of the voltage and current transformers and n and k_n represent the degree and function generator constant, respectively. The actuating condition of the protection is emphasized by the following inequality:

$$\Delta E = K_d\,|\underline{E}_1| - K_d\,|\underline{E}_2| \geq U_0 \tag{3}$$

where K_d is a constant that affects the computed modulus and comparison circuit, and U_0 the sensibility threshold of the measuring element. In many research papers [1], [2], [3], the fulfillment of the condition (3) is considered for the ideal case $U_0 = 0$. This assumes the usage of sensible elements with very low threshold. In practice, U_0 can be decreased, but it is always different from zero and that implies errors both in shape and position between the real and ideal actuating characteristics, in (R, jX) plane. Some considerations concerning these errors for the specific cases of linear ($n = 1$) and quadratic ($n = 2$) function generators usage are further presented.

2 The insensibility influence on the actuating characteristic shapes of the impedance measuring element

2.1 The case of a linear function generator

The actuating condition (3) of protection in case of $n = 1$, $k_n = 1$, becomes

$$|\underline{Z} - \underline{Z}_1| - K_1\,|\underline{Z} - \underline{Z}_2| \geq K_{3L} \tag{4}$$

where:

$$\frac{\underline{U}}{\underline{I}} = \underline{Z}\,,\ \frac{\underline{K}_{1I}}{\underline{K}_{1U}} = -\underline{Z}_1\,,\ \frac{\underline{K}_{2I}}{\underline{K}_{2U}} = -\underline{Z}_2\,,\quad \frac{\underline{K}_{2U}}{\underline{K}_{1U}} = K_1\,,\ \frac{U_0}{K_d K_{1U} I} = K_{3L}\,; \tag{5}$$

For the minimal impedance protection the condition $K_1 > 1$ is added. The following variable transformation is considered in (4):

$$Z_a = |\underline{Z} - \underline{Z}_1|\,,\ a = Arg(\underline{Z} - \underline{Z}_1) \tag{6}$$

Denoting as:

$$|\underline{Z}_1 - \underline{Z}_2| = a\,,\ \frac{Z_a}{|\underline{Z}_1 - \underline{Z}_2|} = v\,,\qquad (7)$$
$$\frac{U_0}{K_d K_{1U} I\,|\underline{Z}_1 - \underline{Z}_2|} = K_{2L}$$

the coordinate system can be changed from (R, jX) into the adimensional system $(R'/a, jX'/a)$. Thus, the actuating characteristic equation becomes:

$$(1 - K_1^2)v^2 + 2(K_1^2 \cos a - K_{2L})v + \qquad (8)$$
$$+ K_{2L}^2 - K_1^2 = 0$$

An ideal actuating characteristic in shape of a circle, with radius w_i and abscissa of the center U_i given by the following:

$$w_i = \frac{K_1}{K_1^2 - 1}\,,\ U_i = \frac{K_1^2}{K_1^2 - 1} \qquad (9)$$

is obtained. For that, $K_{2L} = 0$ $(U_0 = 0)$ and $K_1 = 1$, can be defined.

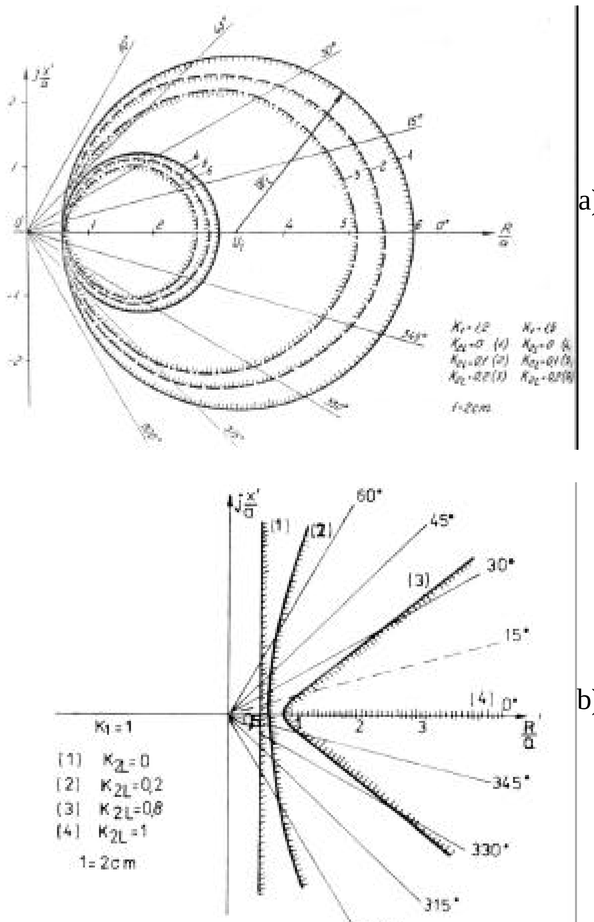

Fig. 2. The actuating characteristics in case of linear function generators: a) $K_1 = 1{,}2$ and $1{,}5$; b) $K_1 = 1$

The ideal characteristic defined above is used as a term of comparison for the evaluation of real characteristic deviations. In Fig. 2a-2b, families of actuating characteristic for different values of K_1 and K_{2L} parameters, are presented. From Fig. 2a-2b, a change of the actuating characteristic of impedance relay by an increase of U_0 and evaluated by means of K_{2L}, results.

Thus, the circular characteristics obtained for $K_1 > 1$ and $K_{2L} = 0$ (the curves 1 and 4 in Fig. 2a) become closed curves, different from circles for $K_{2L} \neq 0$, (curves 2, 3 and 5, 6 in Fig. 2a). The characteristic of the resistance relay obtained for $K_1 = 1$ and $K_{2L} \neq 0$, (the curve 1 in Fig. 2b), changes into a hyperbola type characteristic, (the curves 2, 3 in Fig. 2b). In case that $K_{2L} = K_1 = 1$, a degenerated characteristic with the actuating zone reduced to a line, is obtained, (curve 4 in Fig. 2b).

2.2 The case of quadratic function generator

The condition (3), for the case $n = 2$ and $k_n = K_M$ has the following expression:

$$|\underline{Z} - \underline{Z}_1|^2 - K_1^2\,|\underline{Z} - \underline{Z}_2|^2 \geq K_{3P}^2 \qquad (10)$$

where: $\underline{Z}_1$, $\underline{Z}_2$, K_1 and $\underline{Z}$ are given by (5) and

$$K_{3P}^2 = \frac{U_0}{K_d K_M K_{IU}^2 I^2} \qquad (11)$$

Making a change of variables, similar to that in paragraph 2.1, using (7) and denoting as:

$$K_{2P}^2 = \frac{K_{3P}^2}{a^2} = \frac{U_0}{K_d K_M K_{IU}^2 I^2\,|\underline{Z}_1 - \underline{Z}_2|^2} \qquad (12)$$

the equation of the actuating characteristic in the new, adimensional system becomes:

$$(1 - K_1^2)v^2 + 2vK_1^2 \cos a - K_{2P}^2 - K_1^2 = 0 \qquad (13)$$

where a and v are given by (6) and (7). For $K_1 \neq 1$, in the new axes system, the equation (13) represents a family of circles, no matter the constant value of K_{2P}. In the specific case $K_1 > 1$, $K_{1U} \neq 0$ the circles have the center situated on the real positive axis, with abscissa and radius given by the following relations:

$$U = \frac{K_1^2}{K_1^2 - 1}\,,\ w = \frac{\sqrt{K_1^2 - K_{2P}^2 (K_1^2 - 1)}}{(K_1^2 - 1)} \qquad (14)$$

In Fig. 3, the actuating characteristics described in (13) for the same values of K_1 as in Fig. 2 case and $K_{2P} = K_{2L}$, are presented. The characteristics are placed inside the ideal characteristics $K_{2P} = 0$, and practically, are identical to this. Moreover, in the same conditions referred to the value of constant K_1 and for $K_{2P} = K_{2L}$ the characteristic deformation when using the quadratic functions is lower than in case of the linear functions. For $K_1 = 1$ and $K_{2P} = K_{2L}$ the actuating characteristics becomes lines with displacement from the ideal line ($K_{2P} = 0$), and $R'/a = 0.5$ (see curve 1, Fig. 4). When using the quadratic functions, the displacement of the characteristics is lower than in case of the linear functions, too. Thus, the distance protection errors are lower.

3 Conclusions

In the presence of unavoidable U_0 insensibility of the measuring element used in distance protection schemes, differences in shape and position between the actual and ideal actuating characteristics exist.
The insensibility of the measuring element has a reduced influence in case of using quadratic functions by comparison with linear functions. When using quadratic functions only their position is modified.

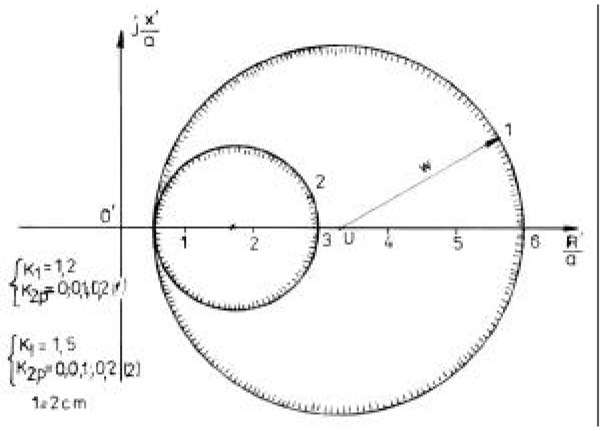

Fig. 3. The actuating characteristics in case of quadratic functions generators for $K_1 = 1{,}2$ and 1,5 and $K_{2L} = K_{2P}$

A qualitative and quantitative evaluation of the impedance measurement errors could be obtained by introducing an error index that would take into account the actual impedance measured value, v and a, and the actual position in the plane (R, jX) or $(R'/a, jX'/a)$ in rapport an ideal work characteristic. The study of the extended n-degree function case is only theoretical as long as functions with a bigger than two degree are not used in practice.

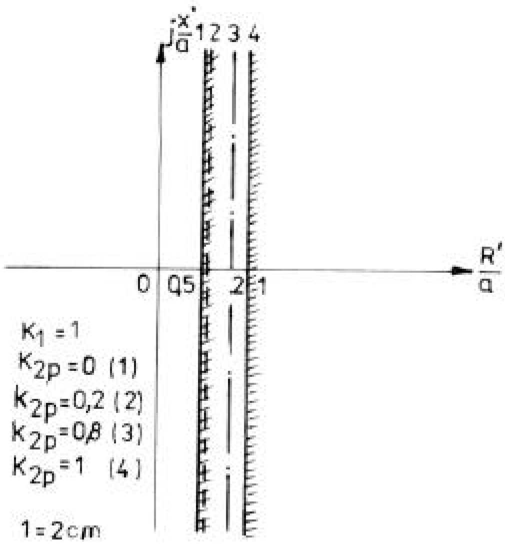

Fig. 4. The actuating characteristics in case of quadratic functions generators for $K_1 = 1$ and $K_{2L} = K_{2P}$

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