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ANALYSIS OF THE OPERATION OF A TYPE AC RCD UNDER RESIDUAL CURRENT DISTORTION CONDITIONS

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Abstract: This article presents an analysis of the operation of a type AC RCD, protecting a circuit in which a nonlinear load is connected. The study was conducted for various power factor (PF) values, simulating circuit leakage until the differential circuit tripped the RCD. This approach allowed for the acquisition of RCD performance characteristics under various load current distortion conditions. The experimental data presented were analyzed, and final conclusions were drawn.

Keywords: RCD, current distortion, shock protection, power quality.

1. INTRODUCTION

Changing the operating conditions of modern electrical installations makes it necessary to constantly update the regulations and technical solutions applicable in the field of electric shock protection. This is conditioned not only by the development of technology itself and the new possibilities appearing with progress, but also by the rapidly increasing saturation of electrical installations with consumers that have a variable nature of operation, introduce disturbances, e.g. in the form of current deformation, or are a source of interference in the field of electromagnetic compatibility [Sadkowski et al., 2024]. Power electronic systems, switching power supplies, inverters and equipment with speed control become sources of this type of

deformation. Moreover, in modern systems, the problem of the presence of voltage and current harmonics and high-frequency components generated by modern electronic equipment is becoming increasingly noticeable. The flow of such currents into the ground through parasitic capacitances and EMC filters creates complex non-sinusoidal waveforms in the leakage circuit [Schneider, 2026]. The issues of energy quality concern both the power generation sector and the consumption sector, as well as the related areas of protection and electric shock protection technology [Czapp et al., 2024; Brodzicki et al., 2025]. The presence of a DC component or the presence of impulse currents requires the use of appropriately selected electrical apparatus, i.e. dedicated residual current circuit breakers (RCDs).

1.1. REFERENCE TO STANDARDS AND NORMATIVE DOCUMENTS

The regulations on the use of residual current equipment concern both the obligation to use them and their rated residual current. The PN-HD 60364 Low-voltage electrical installations [PKN1, 2009; PKN2, 1999] standard indicates that the obligation to use residual current circuit breakers should cover sockets and all rooms equipped with a bathtub/shower. Supplementary protection in electrical installations, in such a case, is implemented by highly sensitive residual current equipment with a residual current (leakage current) of $I_{\Delta n} \leq 30$ mA.

The different types of residual current equipment currently differ, such as in their suitability to operate under the influence of a specific shape of residual current waveform [Czapp, 2011; PKN3, 2013; PKN4, 2013]. The most common in low-voltage general-purpose installations are AC circuit breakers, which detect only sinusoidal current in reference to the mains frequency. To isolate residual currents that contain constant, harmonic components and for higher frequencies, circuit breakers of type A, B and F are used. The prevalence of the use of type AC RCDs in general purpose installations may result from the investment savings of installers and investors, because the prices of type AC RCDs, compared to other types, seem to be one of the conditions for their selection, while the expected effect in the form of supplementary protection in the installation is thus seemingly met at a lower cost than, for example, in the case of a type A residual current equipment.

1.2. EXCLUSIONS ON THE USE OF SELECTED TYPE AC RCD BREAKERS

The limitations of using type AC RCDs result directly from the nature of their operation. The breaker measuring system is sensitive only to a sinusoidally varying current. Any introduction of deformation may therefore make them insensitive to leakage current detection. A constant component, typical for rectifiers and switched-mode power supplies, may lead to a phenomenon known as “blinding” of the differential circuit breaker and cause the loss of the ability to detect both direct and alternating currents. This is due to the operation of the Ferranti transformers found in type AC differential circuit breakers, which require a variable magnetic flux to function properly. The

phenomenon of such incorrect operation, described as “nuisance tripping”, may manifest itself both in the failure of the circuit breaker to operate and in an undesirable effect in the range of currents below the nominal. The observed trend of phasing out equipment of this particular type in domestic installations in other countries [WorkSafe, 2023] in favor of other types of RCDs is therefore the result of safety considerations. In the recommendations given by installers and designers, there are direct indications for the use of circuit breakers of at least type A, which are capable of detecting both sinusoidal currents and pulsating direct currents. The next part of the article attempts to analyze the operation of a type AC residual current device under leakage current deformation conditions during laboratory tests.

A case was considered in which a load was connected to the circuit of a plug socket protected by a highly sensitive type AC residual current device, causing a deformed current to occur in the circuit supplied with a sinusoidal voltage. Assuming that the study may reflect cases occurring when using loads in typical home installations that cause the disturbances mentioned at the beginning of the article, tests were carried out on an RCD, paying particular attention to determining the RMS value of the tripping current.

2. TEST BENCH DESCRIPTION

2.1. TESTED RCD DESCRIPTION AND PRELIMINARY VALIDATION

For the purpose of testing the RCD breaker, a laboratory stand was built consisting of the tested device, a load forcing system with a variable power factor (PF), and a measuring and recording system.

A Schneider Electric Acti9 iID-25-2-30-AC type AC RCD was selected for testing, and the catalog parameters of the tested device are presented in Table 1.

Table 1. Selected catalog parameters of the tested RCD

RCD type Acti9 iID-25-2-30-AC		
Type of RCD	Type AC Residual Current Circuit Breaker (RCCB)	
Nominal current (I_n)	25 A	
Leakage current sensitivity ($I_{\Delta n}$)	30 mA	
Delay type	Instantaneous breaker	
Mains frequency (f)	50/60 Hz	
Nominal voltage (U_e)	220...240 VAC	
Trigger technology	Voltage independent	

Source: [Schneider, 2024].

To assess the correct operation and determine the actual leakage current value before the planned laboratory study, the device was initially tested. The Sonel MPI-502 multifunctional electrical installation parameter meter was used for the check [Sonel, 2022] and this verification was conducted in accordance with the provisions of the standard [PKN5, 2008] for general use RCDs. The following tests and checks were carried out:

1. Functional test and measurements of the shutdown time for the rated current and its multiples.
2. Trip current (actuation current).
3. Touch voltage.

The results of the breaker checks are presented in Table 2.

Table 2. Parameters of the tested RCD

RCD type Acti9 iID-25-2-30-AC	
Functional test	The "T" button turns off correctly
Actuation current $I_{\Delta n}$ [mA]	25.8
Shutdown time t_A [ms] for $I_{\Delta n}$	30
Shutdown time t_A [ms] for $0.5I_{\Delta n}$	No reaction
Shutdown time t_A [ms] for $5I_{\Delta n}$	7
Touch voltage	0.1 V (does not exceed 50 V)

Source: own study.

2.2. TEST BENCH DIAGRAM

The tested breaker was installed on a laboratory stand, see the conceptual diagram in Figure 1.

The stand, in addition to the tested RCD, included a current forcing system in the circuit simulating the load and, in the circuit, simulating the leakage, constructed from GW Instek AEL-5002-428-18.75 electronic loads, which are used to support the measurements of batteries, UPS, fuses and circuit breakers of various types by using different selectable load modes. The system of extraction, together with the current value change program introduced in the leakage circuit, allowed the representation of a real situation in which the tested unit powers the mains socket with the load connected and enabled the leakage current value to be changed in the range from 15 mA to 30 mA, thus covering the expected area of correct operation of the tested RCD.

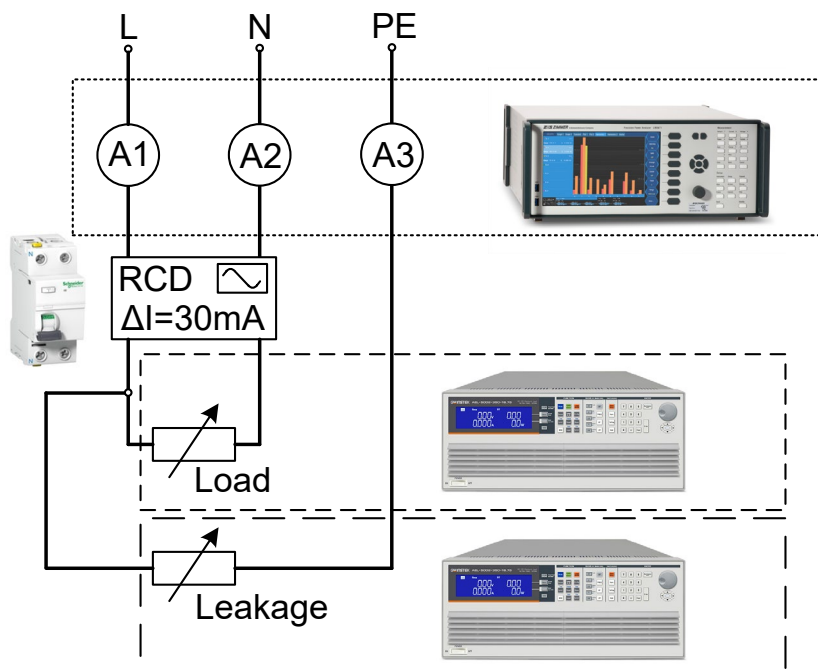


Figure 1. Diagram of the test bench.

A1, A2, A3 current measurements implemented by LMG 671 Analyzer.

“Load” and “Leakage” implemented by AEL-5002-428-18.75 electronic loads

Source: own study based on [GWInstek, 2025; Schneider, 2024; ZES, 2024].

2.3. MEASUREMENTS CIRCUIT

The current measurement was carried out using the current tracks of the LMG671 Zes Zimmer precision power analyzer, which also enabled the recording of measurements with a time resolution of 10 ms. The recordings were then written to computer memory and processed to obtain the collective characteristics presented later in this article.

2.4. POWER SUPPLY

The system was powered from a three-phase laboratory autotransformer, and one of the phases as well as the neutral wire was used for the research. Figure 2 shows the shape of the supply voltage characteristics observed in the measuring system. The noticeable deformations of the U_z supply voltage waveform itself were assumed to be correct because the recorded voltage fluctuations, asymmetry and THD harmonic contents did not exceed the normative values according to PKN6 2010 and MKiŚ 2023 or the local energy company standards for the laboratory location.

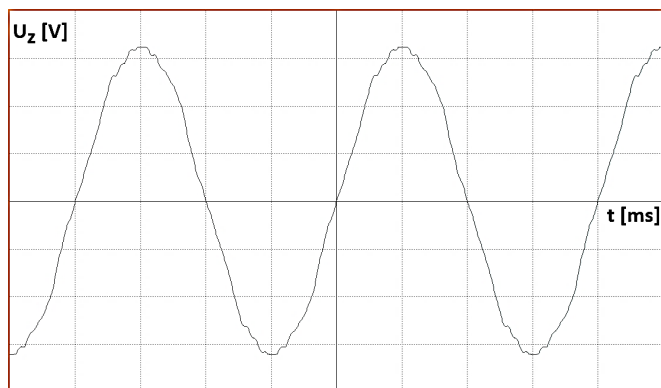


Figure 2. Shape of the supply voltage waveform in the measuring system.

Dimensionless drawing. The voltage waveform is given to illustrate the deformation of the supply voltage not beyond the normative distortion (description in the text above)

Source: own study.

2.5. ELECTRONIC LOADS

The use of electronic loads in the system allowed the implementation of a load program for various values of PF, which in the analyzed case was proportional to the current strain, since there was no phase shift between voltage and current in the system.

2.6. ADOPTED LOAD CIRCUIT AND LEAKAGE CIRCUIT CURRENT DEFORMATION

The method of realizing deformations in the simulated load circuit and in the leakage current circuit for selected PF coefficients is shown in Figure 3. The choice of this type of deformation was not intended to represent a specific type of load. The main goal of the strain load implemented in the study was to change the PF itself and to select a waveform shape that would also give an unusual relationship between the PF and the voltage RMS value. In view of the above the nature of the deformation, which introduced the type of load used, caused the maintaining of a certain RMS value of the forcing current, the peak value of the current increasing with decreasing PF.

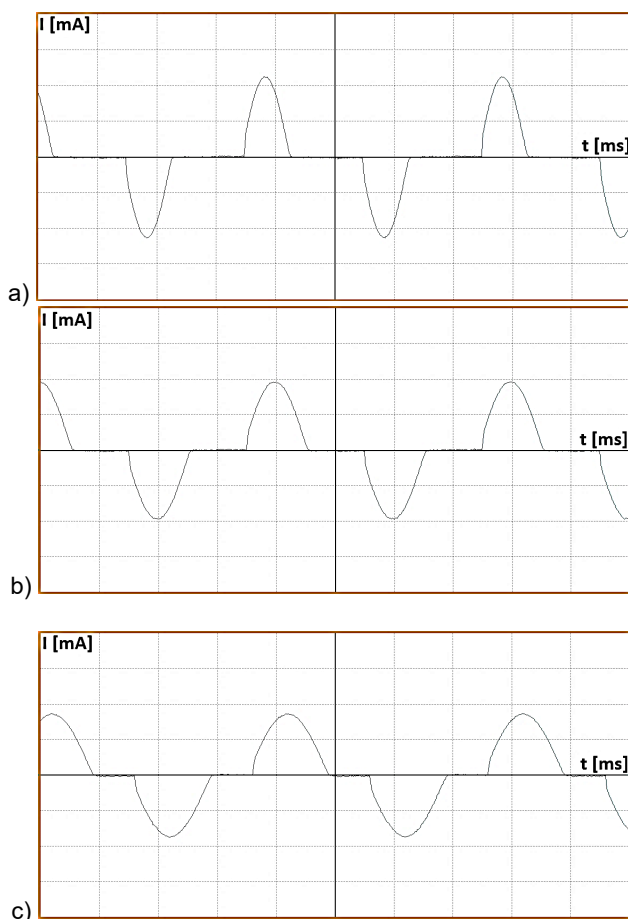


Figure 3. The effect of changing the PF coefficient on the shape of the waveform current. The same current RMS value was maintained on each characteristic. Dimensionless drawing. The current waveform is given to illustrate the type of deformation used during tests. a) $PF = 0.5$; b) $PF = 0.7$; c) $PF = 0.9$

Source: own study.

3. RESEARCH METHODOLOGY

During the test of the residual current equipment, the leakage current value was subject to change while a constant load current value was maintained with a constant value. The test was performed for selected different values of PF in the load circuit and in the leakage circuit.

The supply voltage value at the L-N terminals (Figure 1) was set at 230 V and the current value in the load circuit at 0.5 A, which can represent various types of a domestic use, electronic low power load connected to the power socket.

The circuit breaker test was conducted in three stages, each of which concerned a different situation in which leakage occurred:

1. The first stage involved changing the PF coefficient simultaneously in the load circuit and in the leakage circuit, which simulated a situation close to real conditions observable in electric installations protected by an RCD.
2. The second stage of the study covered the observation of the influence of changing the PF coefficient value only in the load circuit. Although this situation does not correspond to real conditions, this study aimed to verify the sensitivity of the differential element to the variation of the load current flowing through the breaker.
3. The last stage concerned the reverse situation in comparison to the second stage: the PF coefficient was subject to change only in the leakage circuit.

As a result of the test, the characteristics of the current change in the leakage circuit as a function of the PF coefficient were obtained, which allowed the determination of the activation threshold of the RCD expressed in the effective value of the current. The final stage of the test was to plot the characteristics of the RCD trip current value against the degree of current distortion in the load circuit during the same time that this current elapsed.

4. RESEARCH RESULTS

The study of the effect of simultaneous change of the PF coefficient in the load circuit and in the leakage circuit showed and confirmed that there was a close relationship between the current deformation and the trigger threshold of the residual current device, as shown in Figure 4. The notation adopted to describe the obtained curves (e.g. 1.0_1.0) includes an indication of the PF for the forcing in the load simulation circuit and then in the leakage circuit of the circuit breaker under test (ammeters A1 and A3 in Figure 1, respectively). The results obtained are presented below according to the steps described in the previous section.

4.1. STAGE 1

The test was performed for coefficient values $PF = 0.6\text{--}1.0$ with a step of 0.1. The recorded tripping currents of the RCD $I_{\Delta n}$ measured as the RMS value ranged from 25.7 mA for $PF = 0.1$ to 19.5 mA for $PF = 0.6$, with a clear tendency for the activation current value to decrease with the deterioration of the current shape in the circuit associated with the introduced deformation. This phenomenon, called “nuisance tripping”, referred to in the introduction, was indicated as one of the possibilities of

current deformations affecting the operation of a differential circuit breaker, which confirms the initial assumptions.

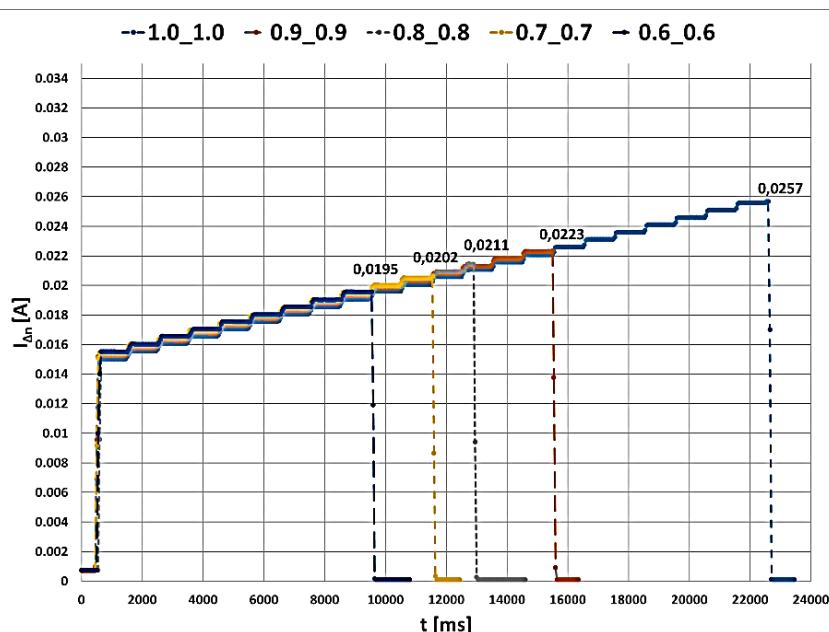


Figure 4. Characteristic of $I_{\Delta n} = f(PF)$ for the variable values of PF in the load circuit and in the leakage circuit.

Source: own study.

4.2. STAGE 2

In order to check whether the theoretical change in the PF coefficient value in the load circuit without affecting the change in the PF coefficient in the leakage circuit was related to the change in the RCD trip current, measurements were performed for PF = 1.0 in the leakage circuit with the change in PF in the range of 0.6–1.0 with a step of 0.1 in the load circuit. The “theoretical change” phrase used indicates the lack of connection between the problem and the real situation described earlier. However, the method of construction of the station allowed the separation of the load circuit from the leakage circuit in such a way that, as a result of the test, it was possible to record the current parameters in both circuits independently. It should be noted, however, that the theoretical aspect of this study, not found in real electrical installations, also results from the construction of the tested circuit breaker, in which both circuits (load and differential) are circuits with independent current paths and it is possible to implement forcing as in the present experiment. The test results are presented in Figure 5.

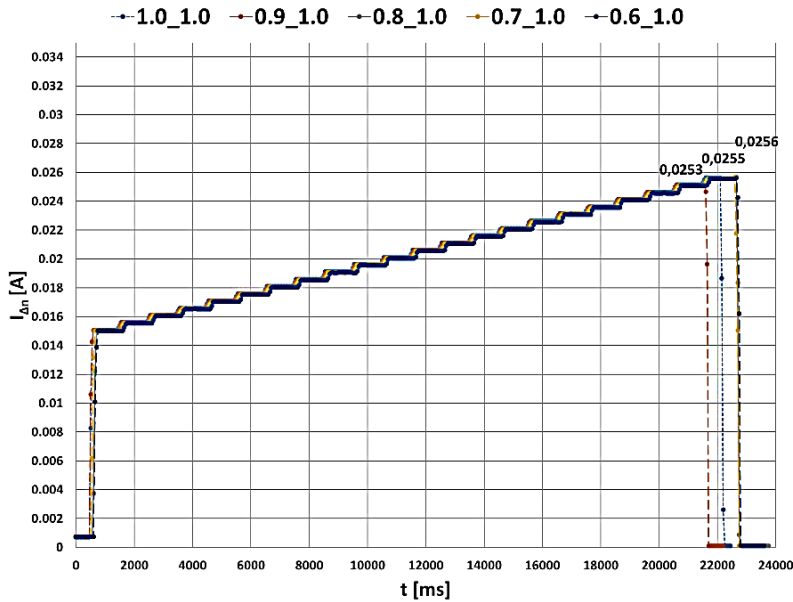


Figure 5. Characteristic of $I_{\Delta n} = f(PF)$ for variable values of PF in the load circuit and constant value of PF = 1.0 in the leakage circuit

Source: own study.

The measurements carried out indicate that the deformation introduced only in the current path of the RCD does not cause a significant reduction in the tripping current value.

4.3. STAGE 3

In order to verify the observation described above, the sensitivity of the residual current device to the appearance of deformed current only in the protection element was checked in-circuit. This was achieved by introducing a strain of PF = 0.6–1.0 with a step of 0.1 only in the leakage circuit while maintaining PF = 1.0 in the load circuit.

The trigger current values obtained as a result of measurements in accordance with the previously described methodology allowed for determining the characteristics of the tripping current of the tested differential circuit breaker as a function of the PF. The results obtained for coefficients PF = 0.1–1.0 are presented in Figure 7. It should be noted that the measurement carried out during the test was characterized by an error not exceeding the value of 0.024 mA, which is due to the accuracy of the measurement path of the LMG671 analyzer and the measurement method used.

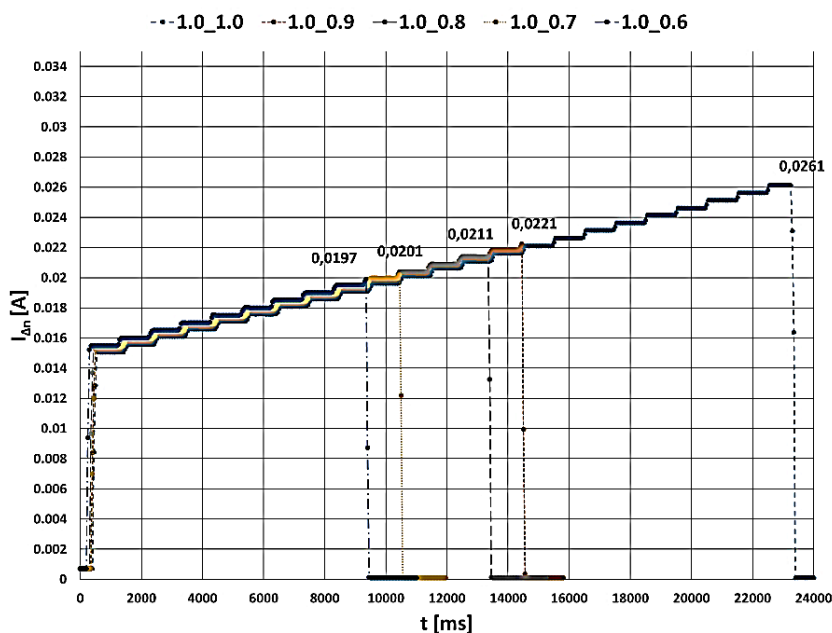


Figure 6. Characteristic of $I_{\Delta n} = f(PF)$ for variable values of PF in the leakage circuit and constant value of PF = 1.0 in the load circuit

Source: own study.

Comparison of the values from the characteristics shown in Figures 4 and 6 allows us to draw the preliminary conclusion that the deformation performed by the electronic load according to the scheme in Figure 3 affects the value of the RCD trip current only when this deformation occurs in the differential circuit.

The trigger current values obtained as a result of measurements in accordance with the previously described methodology allowed for determining the characteristics of the tripping current of the tested differential circuit breaker as a function of the PF. The results obtained for coefficients PF = 0.1–1.0 are presented in Figure 7. It should be noted that the measurement carried out during the test was characterized by an error not exceeding the value of 0.024 mA, which is due to the accuracy of the measurement path of the LMG671 analyzer and the measurement method used.

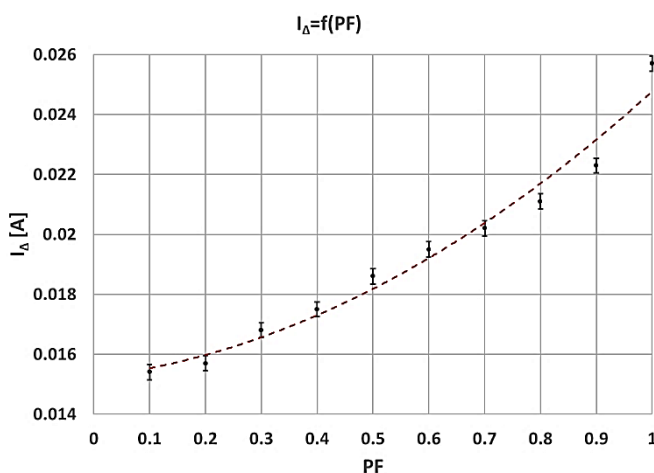


Figure 7. Characteristic of $I_{\Delta n} = f(PF)$ for the tested RCD

Source: own study.

5. ANALYSIS OF THE RESULTS

The conducted tests allowed for the assessment of the influence of the PF on the tripping current value of the tested residual current device. The analysis of the results clearly indicates that for the type of deformation considered there is a clear tendency for the RMS value of the RCD trip current to decrease. It should be noted that, in the current deformation under consideration (Figure 3), as the PF coefficient decreases, the maximum value of the current increases, which results from the need to adjust the relationship between the RMS value and the peak value by changing the shape of the time course to match the PF coefficient.

As the PF coefficient decreases, the tripping current of the tested differential circuit breaker also decreases – so it can be concluded that this is the result of an increase in the peak current value at the deformation introduced by the electronic load used. This is in accordance with the principle of operation of an RCD breaker, in which the appearance of an unbalanced vector sum of currents triggers the relay of the breaker mechanism thanks to the action of the Ferranti transformer, and this difference will be greater at higher current peaks for deformations with a smaller PF coefficient.

It should be emphasized here that the test is carried out only for deformations generated by the type of load used, hence the nature of these changes with deformations of a different type may also be different from that observed.

The theoretical case of current deformation occurring only in the receiver circuit was analyzed, so only in the current path of the tested RCD did it not affect the significant change in the breaker trip current (25.3 mA–25.6 mA).

Checking the effect of the deformation appearing only in the differential circuit (comparing the characteristics shown in Figures 4 and 6) indicates a similar tendency of the switch activation threshold decreasing with a decreasing PF coefficient.

The obtained characteristic (Figure 7) of the dependence of the actuation current as a function of the PF coefficient indicates that there is a relationship between these quantities, and the decrease in the RMS value of the actuation current with a decreasing PF coefficient is related to the nature of the deformation, which in the considered case increases the peak value of the current in order to maintain the assumed RMS value with decreasing PF (Figure 3). It is worth noting that, in the extreme case, the RMS value of the tripping current approaches the non-tripping threshold specified for this type of breaker as $0.5I_{\Delta n}$.

6. CONCLUSIONS

Type AC RCDs are sensitive to current deformations in the leakage circuit. However, their use limited to sinusoidally alternating current circuits does not exclude the possibility of their accidental or intentional use as a form of supplementary protection in installations, e.g. plug sockets, or in lighting circuits. The role of the installer is to determine whether the AC load is introducing distortions into the circuit that may be reflected in the actual breaker operation parameters.

Given the significant differences in the nature of operation and the impact of various modern electricity consumers on the network environment, it is necessary to update the regulations and guidelines regarding the formal restriction of the use of AC RCDs, similarly to solutions found in other countries. The expected increase in the use of equipment with significant distortion values in households may therefore be a source of concern regarding shock protection in low-voltage home installations. The ongoing modernization of installations to the TN-S standard, especially in older buildings, should also include verification of the supplementary protection used, especially in multi-apartment buildings.

The type and nature of the current deformation, especially in cases where the ratio of the peak value to the RMS value of the current increases significantly, affects the tripping threshold of the breaker and may cause – in extreme cases – operation of the differential circuit breaker at RMS values close to the value of $0.5I_{\Delta n}$, i.e. the threshold of non-operation of the breaker.

There is a need to continuously study the response of complementary shock protection measures to the changing nature of forcing and deformation in protected circuits. In this case, the awareness of designers, investors and installers must follow progress and treat human protection as paramount in the selection of shock protection elements. It is also necessary to pay public attention to the issue of protecting people's lives and health from the effects of the shock current.

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