

Frequency behavior of the residual current devices

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Abstract. This paper presents an experimental investigation into the operating characteristic of residual current devices when in presence of a residual current at a frequency of 60Hz. In order to protect persons and equipment effectively the residual current devices are made to be very sensitive to the ground fault current or the touch current. Because of their high sensitivity the residual current circuit breakers are prone to tripping under no-fault conditions.

1. Introduction

Residual current devices (RCDs) also known as residual current circuit breakers are mostly used in low voltage installations as a protective device against electric shock.

The operation of an RCD can be understood by making an analogy to the flow of water from a heating system. A leak may occur when the pipework is damaged or punctured; in the same way a “leak” of electricity may occur when the isolation of a cable in the circuit is damaged or faulty.

The residual current devices monitor the unbalanced current of live conductors from circuits of distribution and in case the breaker detects a dangerous current then that circuit is disconnected quickly. A fault causes current to flow to earth, this current, which does not flow back via the live conductors is called the earth-fault current and it represents the algebraic sum of the instantaneous values of the currents flowing in the live conductors, from where it has its name, residual current [1].

A person may be subjected to an electrical shock in two manners: direct contact – for example the person touches a damaged live conductor, or indirect contact – the person touches a metal part of an electrical machine or device with an insulation fault. The International Electrotechnical Commission elaborated a Time/Current Zones chart for the effects of AC currents on a human body Figure 1. A maximum permissible value of 30mA is considered safe given the current levels considered dangerous.

In order to protect persons and equipment effectively the residual current devices are made to be very sensitive to the ground fault current or the touch current. Because of their high sensitivity the residual current circuit breakers are prone to tripping under no-fault conditions [2]. To ensure a reliable operation of RCDs, it would be necessary to investigate the tripping characteristics of RCDs under different types of unbalanced current [3].

RCDs currently used in Europe are designed and manufactured according to IEC 61008-1 “Residual current operated circuit-breakers without integral overcurrent protection for households and similar uses (RCCBs) – Part 1: General rules” [4]. Most of the residual current devices available on



the market have a rated frequency of 50Hz and in some cases 50Hz/60Hz, so the device is suitable for both frequency circuits.

Many incidents of a nuisance RCD tripping are reported every day to companies that produce electronic and electrical devices such as residual current circuit breakers, to electricity suppliers and to specialized personal from maintenance companies. For each report, there is an investigation that in majority cases reveals that there are ground faults that lead to excessive leakage currents in other healthy circuits and cause the RCD breakers to trip.

In this standard, the operating current or sensitivity of RCD breakers under the 50/60Hz current it is specified, along with the construction and operating specifications and the values of the nontripping requirements for RCDs under a surge current.

This nontripping characteristic of the RCDs allows them to be “blind” for a short specified period of time, in which the breaker does not trip. This characteristic can be found at a G-type RCD. This was brought as a defining mark for this type of breaker to avoid nuisance tripping.

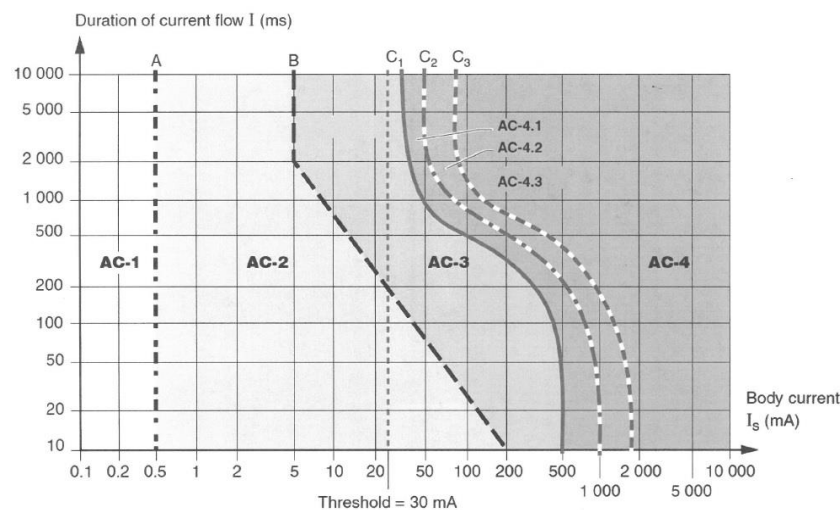


Figure 1. Time/current zones of effects of AC currents (15 Hz to 100 Hz) on persons

However, this standard does not specify the tripping characteristic of RCDs under a current with other waveforms, such as the current containing harmonics, or the surge current with nonstandard waveforms.

A further investigation into the tripping characteristic of the RCDs under a sinusoidal current at rated frequency of 50/60Hz has been carried out by the authors. The RCDs were tested with 50Hz sinusoidal current and with 60Hz sinusoidal current in the laboratory.

This paper presents the results of this experimental investigation as well as discussions. In section I there is a small description of the working principle of an RCD operating system and in section II and III there are presented the tests, the results and the discussions [5].

2. Principle of RCD operation

RCDs are designed to respond to the unbalanced current in a distribution circuit to be protected. When the load is connected to the supply through the RCD, the line and neutral conductors are connected through the primary windings on a toroid transformer.

In this arrangement, the secondary winding is used as a sensing coil and is electrically connected to a sensitive relay or solid state switching device, the operation of which triggers the tripping mechanism. In a healthy and correct circuit, the line and neutral currents are balanced and they produce equal and opposite magnetic fluxes in the toroid core resulting that there is no current generated in the sensing coil [6-8].

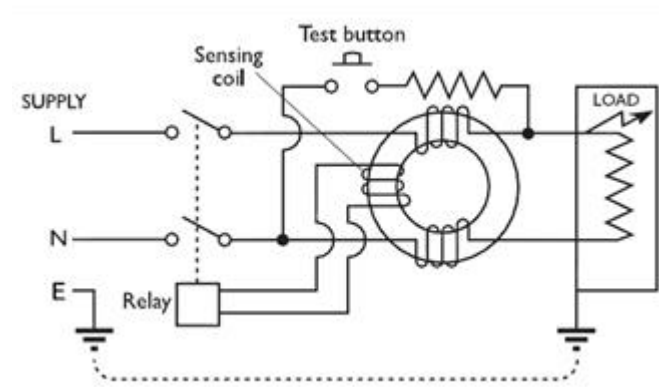


Figure 2. Principle of RCD Operation

When the line and neutral currents are not balanced they create an out-of-balance flux. This will induce a current in the secondary winding of the toroid core, which is used to operate the tripping mechanism. For each RCD breaker, the line and the neutral pass through the toroid. A common cause of nuisance tripping is failure to connect neutral through RCD. This type of breakers is usually build in compliance with single phase, three phase or three phase and neutral circuits.

Tripping current or residual current is an important parameter which characterizes the operating performance of an RCD. There are specified typical values of the rated residual operating current that includes: 6, 10, 30, 100, 300 and 500 mA. The IEC 61008-1 standard requires that the RCD should trip if the value of the residual current is higher than I_{Δ} and -100% and the RCD should not trip if the value of the residual current is smaller than $0.5I_{\Delta} - 50\%$.

There is another specification in the standard that says that when the RCD is subject to an unbalanced surge current of up to 3kA with the 8/20 μ s waveform and of up to 200 or 25 ($I_{\Delta} \leq 10$ mA) with the 0.5 μ s/100 kHz ring waveform.

Table 1. Maximum operating times for G and S type RCDs

Type				
G	Rated Residual Current	I_{Δ}	$2I_{\Delta}$	$5I_{\Delta}$
	Operating time[s]	0.3	0.15	0.04
S	Rated Residual Current	I_{Δ}	$2I_{\Delta}$	$5I_{\Delta}$
	Operating time[s]	0.5	0.3	0.15

AC, type A and type B. The type A or type B RCDs are used in a power circuit with the residual current containing a pulsating or smooth dc component. RCD breakers may or may not be equipped with delay time unit – type S - Selective is a breaker with a short time delay and type G - General is a breaker that has an instantaneous tripping reaction. In this paper there is brought to discussion the general RCD breaker – type G.

The tripping unit of a residual current device contains an electromagnetic relay, a circuit board and a toroid sensing coil. The fault current, via the toroid, supplies energy to an electromagnet whose moving part is held by a permanent magnet. When the operating threshold is reached, the electromagnet counterbalances the attraction of the permanent magnet and the moving part, drawn by a spring, opens the magnetic circuit and mechanically actuates circuit-breaker opening.

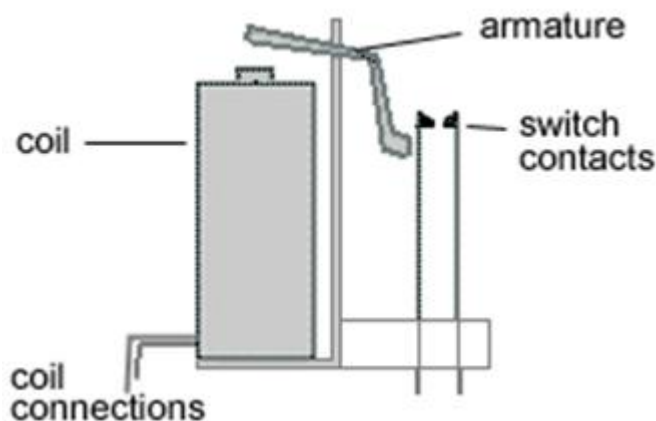


Figure 3. Electromagnetic relay

An RCD is a safety device. Whatever the technology used, it must always be equipped with a test system. Although RCDs without auxiliary sources are the most reliable, implementation of fail-safe systems on RCDs with auxiliary sources offers an enhanced degree of safety that does not, however, replace the periodical test.

For a test, a current is generated that flows in only one of the live conductors surrounded by the toroid. The resistor is sized to let through enough current to trip the RCD, taking into account any leakage currents likely to reduce the test current. The maximum permissible value is 2.5 times $I_{\Delta n}$ (for an adjustable device, $I_{\Delta n}$ is the lowest possible setting).

The above principle is very common because it is the means to check the entire system, i.e. toroid, relay and breaking device. It is used on earth-leakage protection socket-outlets and on residual-current circuit breakers with and without integral overcurrent protection. With respect to residual-current relays with separate toroid, the same principle is sometimes used. Certain relays, for example Merlin Gerin Vigirex relays, are equipped with a built-in “test” function and also continuously monitor the continuity of the detection circuit (toroid/relay link and toroid winding).

The electromagnetic relay consists of a multi-turn coil, with an iron core, together forming an electromagnet. If the coil is energized, by the current passing through it, then the core becomes temporarily magnetized. This magnetized core attracts the iron armature. When the coil is de-energized the armature and contacts are released [9], [10].

The sensor is a toroid transformer. It surrounds all the live conductors and is therefore excited by the magnetic field corresponding to the algebraic sum of the currents flowing in the phases and neutral. The current induced in the toroid and the electrical signal at the terminals of the secondary winding is therefore proportional to the residual current. This type of sensor can detect residual currents from a few mill amperes up to several tens of amperes.

3. Laboratory test setup

For the tests presented in this paper there were used 40 RCD breakers of one brand name. These samples are nonelectronic breakers type G/A, manufactured and assembled according to IEC 61008-1 standard.

All samples have a sensitivity of 100mA and a rated frequency of 50Hz. In this experiment, all samples were subjected to a sinusoidal current waveform at rated frequency and also at a frequency of 60Hz. There were recorded the values of the tripping time when applied a current $5I_{\Delta}$ for all samples.

The laboratory setup used in order to test the breakers it is composed from a current injection system, an oscilloscope and time-measure equipment. The current injection system it is an amplifier that has the capacity to amplify the value of the rated residual current by five, resulting a residual current with a value of 500mA. The current injection system was connected to the terminals of each

RCD breaker tested. The oscilloscope used for the tests presented in this paper had a bandwidth from dc to 200MHz. The time-measure equipment was a digital device with a precision of 0.01s.

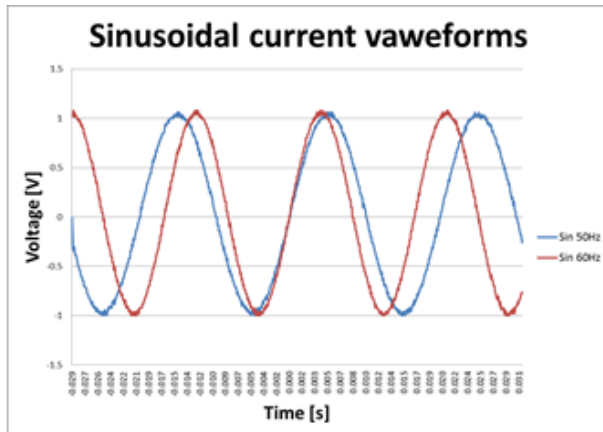


Figure 4. 50Hz and 60Hz sinusoidal current

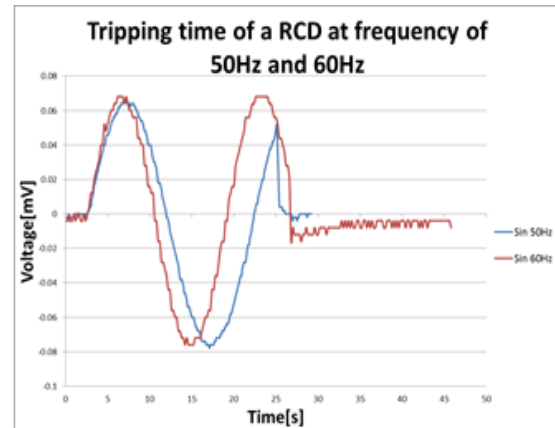


Figure 5. Tripping time of a breaker at 50Hz and 60Hz frequency

4. Steady-State current tests

The shape difference between a sinusoidal current at a frequency of 50Hz and another current sinusoidal with a frequency of 60Hz is highlighted in Figure 4. The shapes of the current were recorded with an oscilloscope. This representation is just for showing purposes and to have in mind the 2 waveforms.

An unbalanced current with a frequency of 50Hz was applied to the RCD sample under test. The test performed on the RCD breaker was a tripping time test, which means that a specific value of the current is applied to the RCD and that the breaker needs to trip in a specified range of time. In case of the G-type and S-type RCDs, the values of the tripping time are presented in Table I.

When applied a sinusoidal current of 500mA, the breaker must trip within 40ms, for 50Hz and 60Hz but not faster than 8.3ms.

In Figure 5 is presented the tripping time of a breaker for 50Hz (blue) and for 60Hz (red). The data presented in Figure 5 was recorded with an oscilloscope. As shown in the graphic from Figure 5, it can be observed that the breaker has a small delay when applied a sinusoidal current of 60Hz than when applied a sinusoidal current of 50Hz.

When applying a sinusoidal current that has a constant value of 500mA at a frequency of 50Hz, the breaker will trip after 1 full period.

In the case of a constant current at 60Hz frequency the breaker will be slightly delayed, tripping after 1 and a half periods. Although, there is a half a period difference between the two tripping time situations, the value of the tripping time is extremely close, for 50Hz frequency the breaker tripped in 25ms and for 60Hz frequency the RCD tripped in 26ms.

Taking this experiment to a larger scale, in the next paragraphs it is presented the tripping characteristic of 40 identical breakers. When testing several breakers that have the same specifications, in the same conditions and with the same equipment the results can highlight the similar behavior of the samples during the tests.

The test can be explained in easy steps:

- A constant unbalanced current with a sinusoidal shape is applied to the terminals;
- At the terminals it is measured the tripping time of the breaker in presence of a residual current with a value of $5 \times I_{\Delta n}$;
- The current shape is monitored on the oscilloscope;

- The value of the tripping time it is measured with a high sensitive chronometer that has a tolerance of 0.01ms;

In Figure 6 there is a graphic of the breaking times of 40ps. RCD breakers G-type when applying a constant sinusoidal current with a value of 500mA, at a frequency of 50 Hz. This test was performed in the same conditions as the first two tests presented in the paper. The average value of tripping time for 40 breakers is 24ms. In Figure 7 is presented the graphic of tripping time for the same 40 RCD breakers G-type when applied a constant sinusoidal current with a value of 500mA at frequency 60Hz.

The values of the tripping time are close with the ones from tripping time 50Hz current. The average value of the tripping time at 60Hz is 24.7ms.

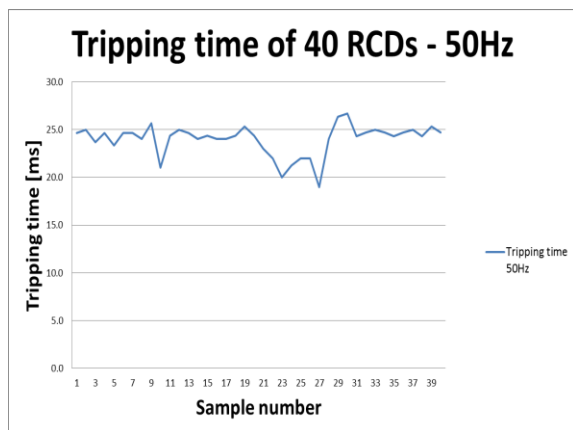


Figure 6. Breaking times at 50Hz for 40 RCDs

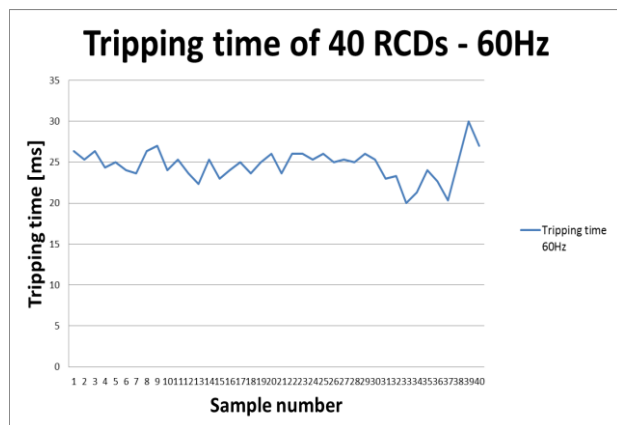


Figure 7. Breaking times at 60Hz for 40 RCDs

5. Conclusions

In conclusion, when applying a constant sinusoidal current constant at a frequency of 60Hz for a G-type breaker, this breaker will be delayed within the limit of a 1ms.

The influence of the toroid transformer, the electromagnetic relay and the electronics board are crucial in operating a residual current device.

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