ELECTRONICS AND ELECTRICAL ENGINEERING

ISSN 1392 – 1215 2008. No. 4(84)

ELEKTRONIKA IR ELEKTROTECHNIKA

HIGH FREQUENCY TECHNOLOGY, MICROWAVES

T191

AUKŠTŲJŲ DAŽNIŲ TECHNOLOGIJA, MIKROBANGOS

The Impact of DC Earth Fault Current Shape on Tripping of Residual Current Devices

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Introduction

One of the most important issues in an electrical installation is effectiveness of the protection against electric shock. The most frequently used means of protection against indirect contact [1] is automatic disconnection of supply, since it is a simple and economically attractive way to achieve safety in electrical installation. As a protective device, residual current devices (RCDs) are commonly used. In certain conditions using the RCDs is necessary [2].

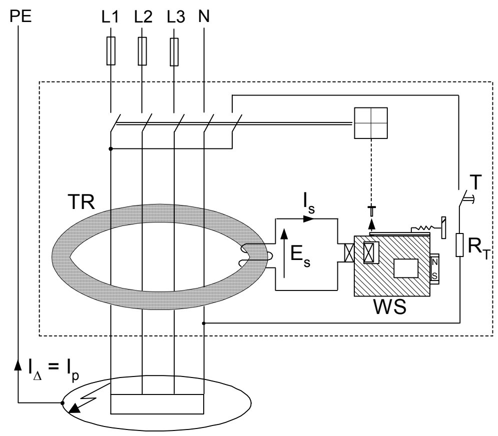


Fig. 1. Simplified diagram of voltage independent type AC or type A residual current device: TR – Ferranti current transformer, WS – electromechanical relay, T – test button, I_p – primary (residual) current, I_s – secondary current, E_s – induced secondary voltage

A residual current device usually comprises coils on a magnetic circuit to carry the phase (three-phase) and neutral current in opposing directions (Fig. 1). In balanced conditions no magnetic flux is generated, but if a fault occurs in the system, the phase and neutral current imbalance induces an electromagnetic force in a secondary circuit, opening the main circuit.

Automatic disconnection of supply occurs if the residual current I_Δ exceeds the RCD rated operating residual current $I_{\Delta n}$. Earth current waveform shape influences the residual current device tripping. From this point of view there are three different types of RCDs:

- AC – for alternating earth current (50/60 Hz),
- A – for alternating and pulsating direct earth current,
- B – for alternating earth current, pulsating direct earth current and smooth direct earth current.

Residual current devices are also applied as an additional protection. In this case the use of residual current devices is intended only to augment other measures of protection against electric shock in normal service. The use of a residual current device with the rated operating residual current not exceeding 30 mA is recognized as an additional protection against electric shock in normal service in case of failure of other protective measures or carelessness of users.

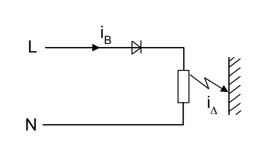
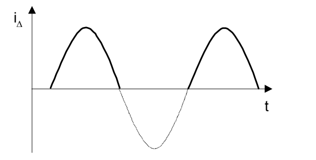
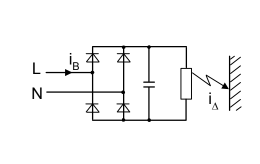
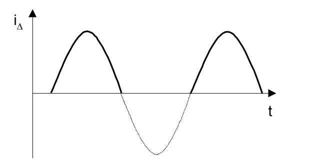
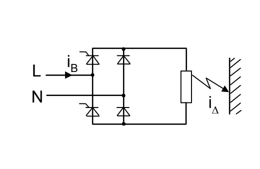
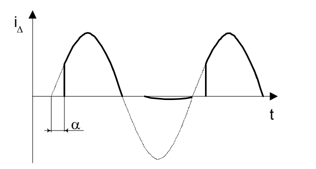
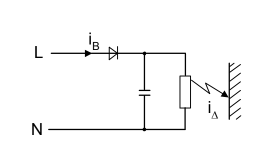
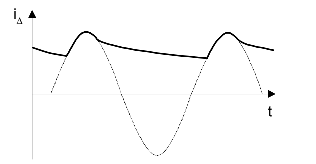
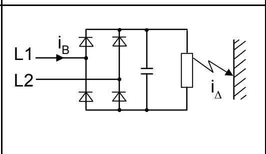
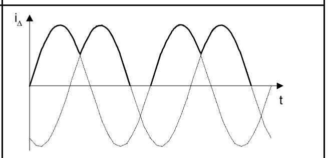
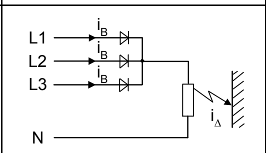
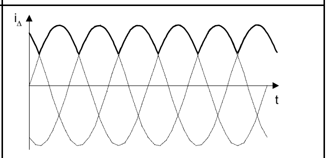
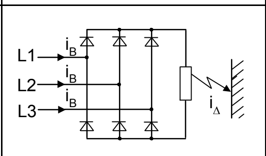
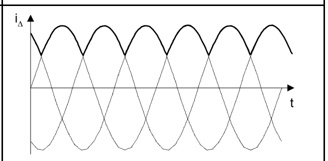
Nowadays the manufacturers of electrical appliances have been using electronic components to improve the performance of their products. Frequency converters for motor rotational speed control are installed in the industry and domestic applications. That equipment comprises different types of rectifiers so in practice it means that DC earth current can occur. Also personal computers and domestic electronic equipment comprise rectifiers. For proper operation of the residual current devices very important is the shape of DC earth current.

Current transformer properties and construction of the secondary circuit of residual current devices are very important for DC earth fault current detection. The following paragraphs present principles of residual current devices operation and laboratory test results if DC earth fault current flows. The laboratory test proved that in some cases the residual current device operational characteristics can be unexpected.

Earth current shape in circuits with rectifiers

The earth fault current shape depends on the type of the rectifiers implemented in the electric or electronic device. Tab. 1 presents earth current shape for different types of rectifiers.

Table 1. Earth (residual) current shape in circuits with rectifiers

No	Rectifier	Earth current
1		
2		
3		
4		
5		
6		
7		

There are the following types of rectifiers: No.1 – half wave rectifier; No.2 – full wave rectifier without phase control; No.3 – full wave rectifier with phase control; No.4 – half wave rectifier with DC filter; No.5 – full wave rectifier supplied L1-L2; No.6 – three-phase rectifier without phase control; No.7 – six-pulse three-phase rectifier without phase control.

The earth fault current in circuits with the rectifiers from No.1 to No.3 is characterised by significant pulsation. If a line to earth short-circuit occurs in circuits with one of the rectifiers from No.4 to No.7, the earth current is almost smooth. Capability of operation of the residual current devices depends on the earth current pulsation.

International standard requirements for RCD operation

Basic requirements for RCD operation are contained in standards [3,4]. The types of tests are described which have to be carried out for particular types of RCDs.

The type AC RCDs are tested under 50/60 Hz sinusoidal AC current and their residual non-operating current shall be $0.5 \cdot I_{\Delta n}$ but the residual operating current $I_{\Delta n}$. The type A RCDs are also tested under pulsating DC currents as in Tab. 2 and under a pulsating current (current delay angle $\alpha = 0°$) with a smooth DC current of 6 mA superimposed on top of it.

Table 2. Tripping current ranges for type A RCDs [3, 4]

Current delay angle α [°]	Residual current	
	non-operating	operating
0	$0.35 \cdot I_{\Delta n}$	$1.4 \cdot I_{\Delta n}$ *
90	$0.25 \cdot I_{\Delta n}$	
135	$0.11 \cdot I_{\Delta n}$	

* for RCDs with $I_{\Delta n} \le 10$ mA residual operating current is $2 \cdot I_{\Delta n}$

The type B RCDs are tested under conditions described above and also under DC currents from:

- full wave rectifier supplied L1-L2 (residual non-operating current = $0.5 \cdot I_{\Delta n}$, residual operating current = $1.4 \cdot I_{\Delta n}$),
- three-phase three-pulse (or six-pulse) rectifier without phase control (residual non-operating current = $0.5 \cdot I_{\Delta n}$, residual operating current = $2 \cdot I_{\Delta n}$),
- galvanic battery – smooth DC current – (residual non-operating current = $0.5 \cdot I_{\Delta n}$, residual operating current = $2 \cdot I_{\Delta n}$),

Testing of the RCD operation

In order to check the influence of DC current shape on the residual current device tripping, over thirty RCDs with rated operating residual current $I_{\Delta n} = 30$, 100, 300 and 500 mA were tested. They were two-pole, four-pole, type AC, type A and type B short-time-delayed and time-delayed (selective) devices. Fig. 2 and 3 present chosen results of the test which was carried out under laboratory conditions.

Almost all the tested type AC residual current devices tripped out only for the sinusoidal AC residual current. However, unexpectedly, a few type AC RCDs tripped out for half wave rectified current and even for full wave rectified current (Fig. 2).

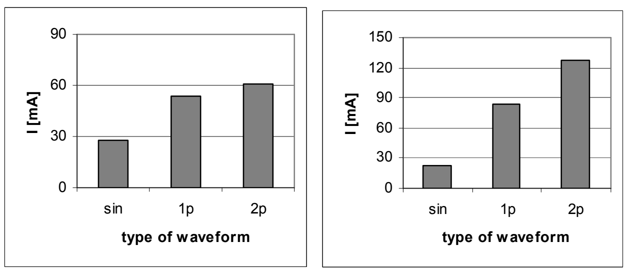
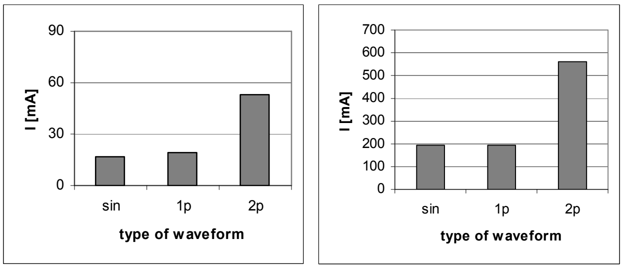


Fig. 2. Tripping current of the RCDs: a), b) $I_{\Delta n} = 30$ mA, type AC, short-time delayed; sin – sinusoidal AC current, a – half wave rectified current, 2p – full wave rectified current

All the type A RCDs operated in accordance with the above mentioned standards for sinusoidal alternating current and half wave residual current. These RCDs operated for full wave rectified DC current but the tripping current was significantly higher then for the half wave residual current and exceeded the permissible limit (Fig. 3).



a) b)

Fig. 3. Tripping current of the RCDs: a) $I_{\Delta n}$ = 30 mA, type A, b) $I_{\Delta n}$ = 300 mA, type A, time-delayed S-type; sin – sinusoidal AC current, 1p – half wave rectified current, 2p – full wave rectified current

The full wave rectified DC current is more unfavourable than the half wave DC current. The phenomenon is explained in Fig. 4.

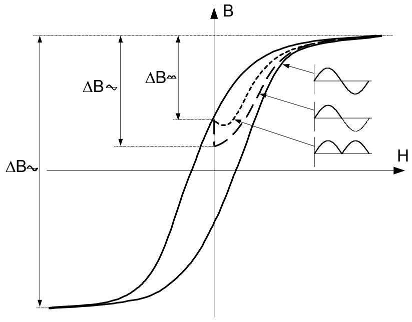
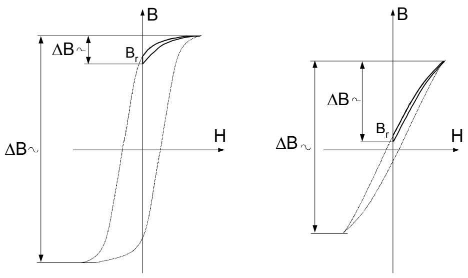


Fig. 4. Histeresis loops of current transformer for different types of the primary DC current

Variation of induction ΔB in the core of the current transformer is higher if the primary DC current has a dead time (half wave current). Then current transformer is demagnetized to the value of induction B_r which is lower than the natural remanence level. Induced secondary voltage is sufficient and the residual current devices trip out.

Detection of a DC residual current is possible only for a current transformer characterised by a flat histeresis loop. Fig. 5 presents the variation of induction for two types of current transformers.

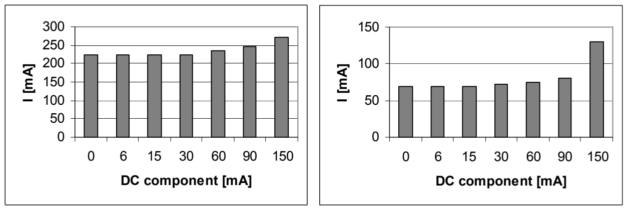


a) b)

Fig. 5. Histeresis loops of current transformers for DC primary current (solid line): a) round – type AC RCDs, b) flat – type A RCDs

Fig. 6 presents the RMS value of tripping current (half wave component) if a smooth DC component is superimposed on the half wave current. During the test the tripping current was checked for the following values of smooth DC component: 0, 6, 15, 30, 60, 90 and 150 mA. The impact of DC component is significant on the type AC RCDs.

Many type A RCDs operated properly if DC component was equal to 150 mA. It was unexpected (Fig. 6) and in some cases particular type A RCDs can be used instead of type B RCDs which are incomparably more expensive. The test has proved that many type A RCDs operate properly if the smooth DC component is much higher than the value (6 mA) required by the standards.



a) b)

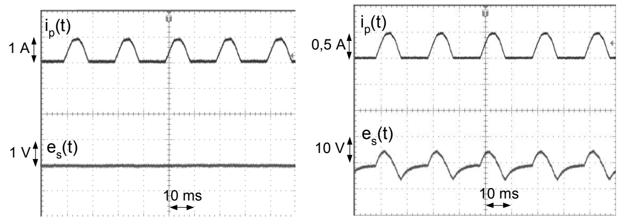
Fig. 6. Tripping current (the RMS value of the half wave component) of the RCDs: a) $I_{\Delta n}$ = 300 mA, type A, b) $I_{\Delta n}$ = 100 mA, type A, time-delayed S-type; The value of a superimposed smooth DC component: 0, 6, 15, 30, 60, 90 and 150 mA

The tested type B RCD operated properly even when smooth DC current flowed, but an auxillary voltage is necessary.

Testing of the current transformers

The aim of the current transformer in the voltage independent RCDs is to deliver sufficient current to the electromechanical relay which is installed in the secondary circuit. Secondary current value depends on the induced secondary voltage. The AC earth current ensures sufficient induced voltage so in consequence the secondary current is high enough, but the problem is if the DC current flows to earth.

Fig. 7 presents induced voltage if the half wave current flows to earth and Fig. 8 presents the same voltage if current from the half wave rectifier with DC filter flows to earth. Both figures contain oscillograms for two types of current tranformer: type AC and type A. The oscillograms show that only special types of current transformes (with flat histeresis loop) may detect DC current. Detection of DC current is possible but the current has to be characterised by significant pulsation.



a) b)

Fig. 7. Induced voltage $e_s(t)$ for half wave earth current $i_p(t)$: a) current transformer for type AC RCDs, b) current transformer for type A RCDs (flat histeresis loop)

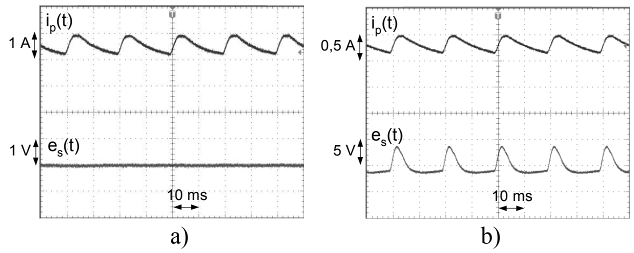


Fig. 8. Induced voltage $e_s(t)$ for earth current $i_p(t)$ from half wave rectifier with DC filter: a) current transformer for type AC RCDs, b) current transformer for type A RCDs (flat histeresis loop)

Conclusion

In modern installations, residual current devices are commonly used. Use of the RCDs increases the safety level of electrical equipment operation. For proper RCD operation in circuits with DC earth current very important is the shape of the current. For many RCDs real operating characteristics are more favourable than those required by the international standards. In some cases, after investigation, it is possible to use much simpler type A RCDs instead of the type B RCDs.

Acknowledgement

This paper is a result of research project financed by Ministry of Science within the **2005-2008** programme.

References

1. **IEC 60364-4-41** Electrical installations of buildings. Protection for safety. Protection against electric shock.
2. **IEC 60364-7-7xx** Electrical installations of buildings. Requirements for special installation or locations.
3. **EN 61008-1** Residual current operated circuit breakers without integral overcurrent protection for household and similar uses (RCCB's). Part 1. General rules.
4. **IEC 60755** General requirements for residual current operated protective devices.

Submitted for publication 2008 01 25

S. Czapp. The Impact of DC Earth Fault Current Shape on Tripping of Residual Current Devices // Electronics and Electrical Engineering. – Kaunas: Technologija, 2008. – No. 4(84). – P. 9–12.

Nowadays the manufacturers of electrical appliances introduce electronic components to improve the performance of their products. Many industrial and domestic devices comprise different types of convertors generating DC earth fault current. The shape of that current influences the RCD tripping. In this paper the impact of DC earth fault current shape on RCD residual operating current is presented and results of laboratory tests are discussed. They prove proper tripping of many RCDs even when the DC component in earth fault current is significantly greater than that required in standards. Results of the DC earth fault current transformation by the Ferranti current transformers are also presented. Ill. 8, tabl. 2, bibl. 4 (in English; summaries in English, Russian and Lithuanian).

С. Цзапп. Воздействие формы потока ошибки земли постоянного тока при легкой походке остаточных текущих устройств // Электроника и электротехника. – Каунас: Технология, 2008. – № 4(84). – С. 9–12.

В настоящее время изготовители электрических приборов вводят электронные компоненты, чтобы улучшить работу их продуктов. Много индустриальных и внутренних устройств включают различные типы конвертеров, производящих поток ошибки земли постоянного тока. Форма того потока влияет на легкую походку RCD. В этой бумаге представлено воздействие формы потока ошибки земли постоянного тока на остаточном операционном потоке RCD, и результаты лабораторных испытаний обсуждены. Они доказывают надлежащую легкую походку многих RCDs, даже когда компонент постоянного тока в земном потоке ошибки значительно больше чем требуемое в стандартах. Результаты преобразования потока ошибки земли постоянного тока текущими трансформаторами Ferranti также представлены. Ил. 8, табл. 2, библ. 4 (на английском языке; рефераты на английском, русском и литовском яз.).

S. Czapp. Nuotėkio srovės klaidos įtaka likusiems einamiesiems prietaisams // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2008. – Nr. 4(84). – P. 9–12.

Elektros prietaisų darbui pagerinti gamintojai naudoja elektrinius komponentus. Daugelis pramoninių ir buitinių prietaisų susideda iš įvairių tipų keitiklių, kuriančių nuotėkio sroves. Tos srovės forma daro įtaką likusiems srovės įtaisams. Čia išanalizuotas nuotėkio srovės poveikis, laboratorinių testų rezultatai yra aptarti. Jie įrodo daugelio likutinės srovės buvimą, net kai nuolatinės srovės komponentas parinktas žymiai didesnis negu tai reikalinga standartuose. Pristatyti nuotėkio srovės einamosios transformacijos prie Ferranti einamųjų transformatorių rezultatai. Il. 8, lent. 2, bibl. 4 (anglų k.; santraukos anglų, rusų ir lietuvių k.).

DOI: 10.5755/j02.eie.11095