ELECTRONICS AND ELECTRICAL ENGINEERING

ISSN 1392 – 1215 *2007. Nr. 4(76)*

ELEKTRONIKA IR ELEKTROTECHNIKA

SIGNAL TECHNOLOGY

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Protection Against Electric Shock Using Residual Current Devices in Circuits with Electronic Equipment

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Introduction

One of the most important things in an electrical installation is effectiveness of the protection against electric shock. Protection in the case of fault is recognized by the use of [4]:

- automatic disconnection of supply,
- Class II equipment or equivalent insulation,
- non-conducting location,
- electrical separation,
- earth-free local equipotential bonding.

The most often used means of protection against indirect contact is automatic disconnection of supply because it is a simple and not expensive way to achieve safety in electrical installation. As a protective device, residual current devices (RCDs) are commonly used. In some conditions using the RCDs is necessary [5].

Many appliances, for example personal computers, switch mode power supply, rectifiers, filters etc., widely used in modern installations, influence operation of the residual current devices. Electronic equipment like frequency converters produce pulsating direct earth current, smooth earth current and alternating earth current with high level of harmonics. In these locations only some RCDs operate properly and guarantee effectiveness of protection against electric shock [2].

RCDs may operate under no risk of electric shock. The problem exists when a circuit with electronic equipment is switched on and transient current with high peak value in the protective conductor flows. In steady state, in normal service leakage current of a significant value may also flow in the protective conductor so it often makes residual current devices nuisance tripping as well. It is important to pay attention to the selection of residual current devices in order to eliminate electric shock risk and achieve reliability of supply.

Principles of the RCDs operation

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, tripping the main circuit.

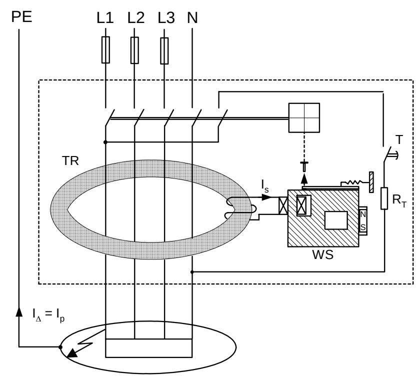

Fig. 1. Residual current device diagram: TR – Ferranti transformer, WS – tripping mechanism, T – test button

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 every kind of earth current.

Effect of the earth current frequency and distortion

This problem is typical of circuits with frequency converters. Frequency converters are commonly used to control the speed of a squirrel cage motors. The first part, starting from the supply side, is a rectifier (Fig. 2). In the second part (intermediate circuit), pulsating DC voltage produced by the rectifier is filtered. The last main part of the frequency converter is inverter which uses DC current or voltage from the intermediate circuit to produce AC current or voltage of a desired frequency. Taking the above into account, the output earth fault current may be from low to high frequency.

It is recognized that for the current frequency 50 Hz, the treshhold of perception – a minimum value of current which under given conditions causes any sensation to person through whom it is flowing – is 0.5 mA. For the same frequency, the threshold of let-go – the current level where control of human muscles is lost and the electricity causes muscles to contract until the current is removed – is 10 mA. The most important is the threshold of cardiac fibrillation. Current of more than 30÷40 mA can be life-threatening because natural rhythm of the heart can be lost.

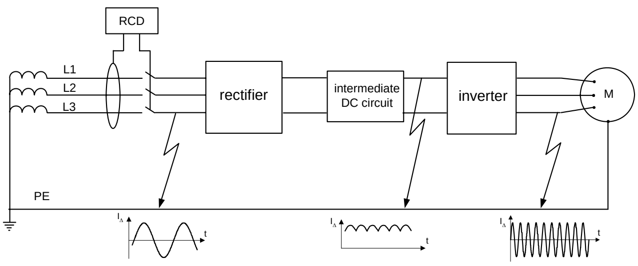

Fig. 2. Earth current waveform shape in the circuit with frequency converter

For the body current of higher frequency, the threshold of perception, threshold of let-go and treshold of ventricular fibrillation move to a higher value. Fig. 3 presents variation of the mentioned threshold values as a function of frequency [3].

For frequency equal to 1000 Hz the treshold of ventricular fibrillation changes from 30÷40 mA to 420 mA. It it is a very important information because in many residual current devices tripping current increases significantly if earth current frequency is higher than 50 Hz.

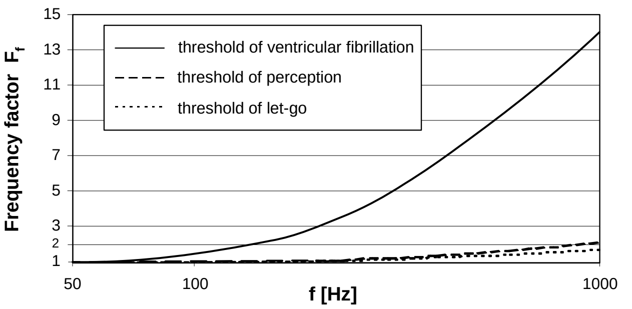

Fig 3. Variation of the threshold of perception, threshold of let-go and threshold of ventricular fibrillation within the frequency range 50 Hz to 1000 Hz

In order to check the influence of current frequency on the residual current devices tripping, over twenty RCDs with rated operating residual current $I_{\Delta n} = 30$, 100 and 300 mA were tested. They were two-pole, four-pole, AC type, A type, delayed and selective tripping devices. Fig. 4 to 6 present chosen results of the test which was carried out under laboratory condition.

Solid trace I_Δ presents tripping current variation for the frequency range 1÷1000 Hz, dashed trace I_f presents threshold of ventricular fibrillation as a function of frequency. Current characteristics presented in Fig. 4 indicate that the tripping current of this RCD depends on frequency. For frequency higher than 50 Hz the I_Δ trace is under the I_f trace, so for the tested frequency range protection against electric shock is effective – ventricular fibrillation doesn't occur.

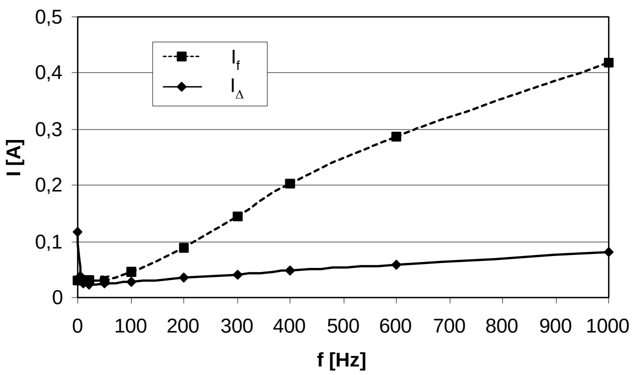

Fig. 4. Tripping current of the RCD: $I_{\Delta n} = 30$ mA, AC type

For the tested RCD whose tripping current is presented in Fig. 5, for frequency higher than 50 Hz tripping current I_Δ is above trace I_f so in such case ventricular fibrillation may occur.

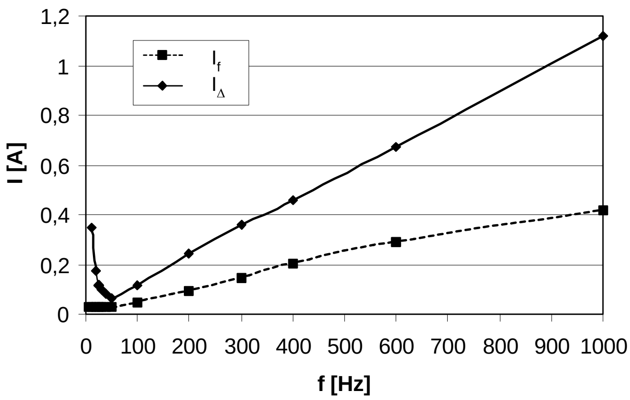

Fig. 5. Tripping current of the RCD: $I_{\Delta n} = 100$ mA, A type, selective S-type

Fig. 6 shows tripping current of RCD whose rated operating residual current is also $I_{\Delta n} = 100$ mA. In this situation, within the frequency range 100 Hz to 600 Hz tripping I_Δ current trace is located under trace I_f. It means that this RCD within the frequency range 100 Hz to 600 Hz is effective as 30 mA RCD for frequency equal to 50 Hz.

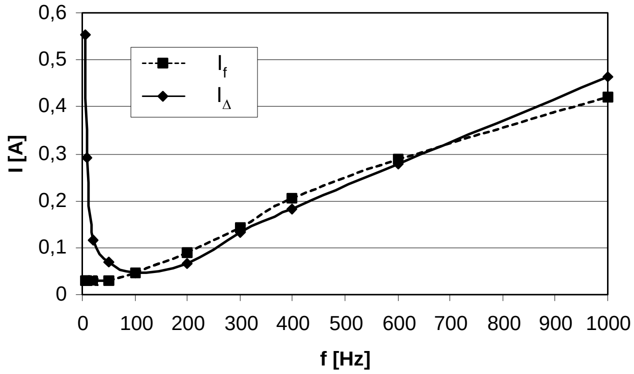

Fig. 6. Tripping current of the RCD: $I_{\Delta n}$ = 100 mA, AC type, short-time delayed tripping

Typical earth current in circuits with frequency converters comprises wide spectrum of harmonics. The level of a particular harmonic may exceed the level of the fundamental harmonic. Fig. 7 presents line to earth voltage on the output terminals of inverter. If earth fault occurs earth current waveform is similar to this voltage waveform.

a) b)

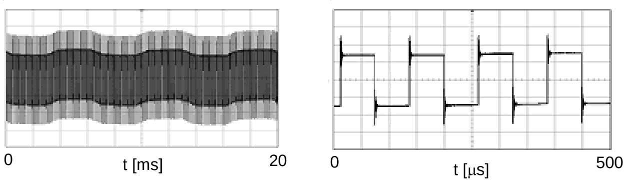

Fig. 7. Line to earth voltage on the output terminals of inverter [6]

Laboratory test has proved that the higher harmonic in earth current the less sensitive are typical residual current devices. Fig. 8a shows result of the test of chosen RCDs. The first RCD was AC type 100 mA and its real operating current for the fundamental harmonic was 70 mA (Fig. 8a). The second RCD was AC type 30 mA and its real operating current for the fundamental harmonic was 23 mA (Fig. 8b). During the test the value of the fundamental harmonic was set a little bit under the operating residual current and a single harmonic from 3rd to 19th was increased. For the first RCD the set value (50 Hz) was 60 mA and for the second RCD 20 mA.

a) b)

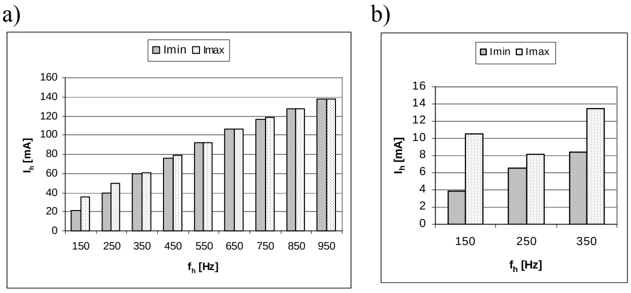

Fig. 8. The effect of harmonic on AC type RCDs tripping current: a) RCD 100 mA, b) RCD 30 mA

The first RCD operated for the whole tested harmonic range but for the 19th harmonic its participation in earth current exceeded twice the fundamental (140 mA). The second RCD operated only to the 7th harmonic. For the 9th harmonic the second RCD didn't operate even if this harmonic was five times the fundamental. In order to make this RCD trip, the fundamental harmonic was increased. The tested RCD operated when the fundamental harmonic was 45 mA. Test indicated that high level of harmonics in the earth current may decrease the RCD sensitivity to the fundamental harmonic.

Transient and steady state leakage currents

Process of switching the electronic appliances often generates transient earth current with high peak value. Many circuits with electronic appliances were tested by the author. Fig. 9 presents line voltage and protective conductor current during switching a personal computer unit. Current peak value is almost 8 A.

Fig. 10. presents protective conductor current during switching 7 personal computer units. After high transient current, steady state current flows in the protecive conductor. When one circuit feeds many personal computers, protective conductor transient current may exceed 20÷30 A and steady state protective conductor current may exceed 10 mA.

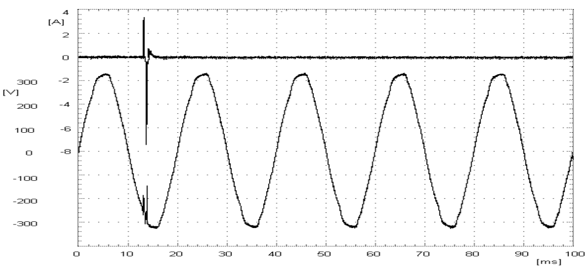

Fig. 9. Leakage current in the protective conductor (top trace) and line voltage (bottom trace) during switching personal computer unit. Current peak value I_{peak}= 7,8 A

Electrical installation designer who is selecting RCDs should be aware of features of the electronic equipment to be installed in a particular circuit in order to avoid protective devices unwanted tripping. It is recommended to install in those circuits short-time delayed or selective type RCDs.

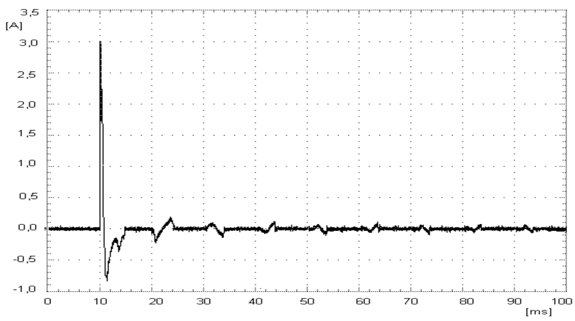

Fig. 10. Leakage current in the protective conductor during switching 7 personal computer units. Current peak value I_{peak} = 3,0 A

The use of residual current devices in circuits with frequency converters also results in the problems of their unwanted tripping. In the frequency converter circuits transient and steady state leakage current may flow.

Steady state current may reach the value of 200 mA. This excludes the use of residual current devices with high current sensitivity (30 mA). Also parasitic capacity causes significant current in the protective conductor. This current has impulse spectrum with frequency which depends on the Pulse Width Modulation (PWM). Fig. 11 presents the waveform of current in the protective conductor in the circuit with frequency converter. The analysis of two waveforms presented in Fig. 11 indicates that through the motor construction, and in conseqence through earth, flows leakage current twice as strong as in the protective conducor.

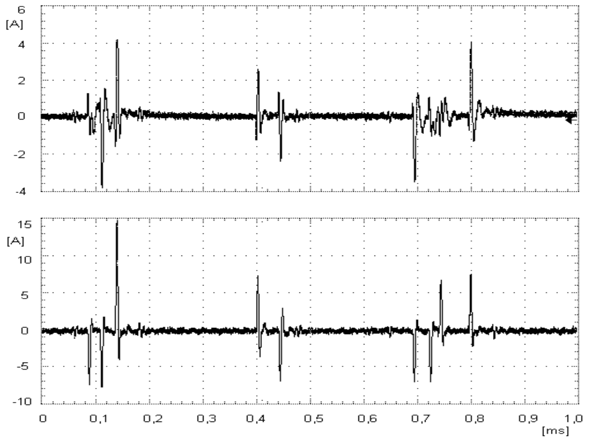

Fig. 11. Leakage current in the protective conductor (top trace) and current flowing through the motor construction (bottom trace) in the circuit with frequency converter. Load 4×3 kW, frequency 50 Hz [1]

Conclusion

In modern installations, residual current devices are commonly used. Use of the RCDs increases the safety level of electrical equipment operation. However, selection of the residual current devices has to be performed very carefully. In circuits with electronic equipment distorted earth current may occur. Only certain types of residual current devices operate in these cases. In some situations AC and A type residual current devices are sufficient but tripping current as a function of frequency should be known. Sometimes expensive B type RCDs or other means of protection should be applied.

Acknowledgement

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

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Submitted for publication 2007 02 15

S. Czapp. Protection Against Electric Shock Using Residual Current Devices in Circuits with Electronic Equipment // Electronics and Electrical Engineering. – Kaunas: Technologija, 2007. – No. 4(76). – P. 51–54.

One of the means of protection in the case of fault in low voltage systems is automatic disconnection of supply. Automatic disconnection of supply is required where a risk of harmful pathophysiological effects on humans can arise, resulting from dangerous touch voltage. In order to fulfil this requirement, residual current devices (RCDs) are used as protective devices. In circuits with electronic equipment various frequencies and distorted earth fault current can occur. The analysis indicates that earth fault current frequency other than the rated value often causes improper operation of RCDs. In some cases the protective device cannot trip at all and thus protection against electric shock is not effective. In circuits with electronic equipment transient and steady state leakage current can occur so it causes the RCDs unwanted tripping. This paper presents special problems of selection and operation of RCDs in circuits with electronic equipment, based on the laboratory and field investigations. Ill. 11, bibl. 6 (in English; summaries in English, Russian and Lithuanian).

С. Цзапп. Применение реле утечки тока для защиты от сверхнапряжения электрических устройств // Электроника и электротехника. – Каунас: Технология, 2007. – № 4(76). С. 51–54.

Описываются методы защиты устройств от сверхнапряжении. Показано, что оптимальное решение – это автоматическое отключение сети с помощью реле, когда это необходимо для обеспечения безопасности обслуживающего персонала. Предлагается, что в таких электрических цепях целесообразно использовать частоты, построенные на основе контакта полюса земли. Всесторонне анализируются оптимальные условия выбора режимов реле и операций в электрических цепях. Приводятся теоретические и экспериментальные результаты. Ил. 11, библ. 6 (на английском, русском и литовском яз.).

S. Czapp. Elektrinės įrangos apsauga nuo viršįtampių naudojant srovės nuotėkio reles // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2007. – Nr. 4(76). – P. 51–54.

Išnagrinėta elektrinės įrangos apsauga nuo viršįtampių naudojant srovės nuotėkio reles. Automatiškai atjungiamos tos grandinės, kurios yra pavojingos žmogaus gyvybei. Tokiose grandinėse srovės nuotėkio relės naudojamos kaip apsauginis elementas. Elektrinėse grandinėse gali būti sukuriami pašaliniai dažniai žemės poliaus kontakto pagrindu. Dėl jų srovės nuotėkio relė veikia netinkamai. Pašalinės srovės gali būti ir trumpalaikės, ir nuolatinės; pastaruoju šiuo atveju grandinė atjungiama. Čia išnagrinėtos problemos, susijusios su srovės nuotėkio relės parinkumu ir operacijomis elektrinėse grandinėse. Atlikti tiek teoriniai tiek praktiniai tyrimai. Il. 11, bibl. 6, (lietuvių kalba; santraukos anglų, rusų ir lietuvių k.).