ELECTRONICS AND ELECTRICAL ENGINEERING
ISSN 1392 – 1215 2009. No. 3(91)
ELEKTRONIKA IR ELEKTROTECHNIKA

ELECTRICAL ENGINEERING
T190
ELEKTROS INŽINERIJA

Elimination of the Negative Effect of Earth Fault Current Higher Frequency on Tripping of Residual Current Devices

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Introduction

In low voltage electrical installations residual current devices (RCDs) are used for protection against electric shock (Fig. 1a, Fig. 1b) and protection against a fire caused by leakage currents (Fig. 1c). There are two types of protection against electric shock:

– against indirect contact – a residual current device shall disconnect supply in case of electrical equipment insulation earth fault,
– against direct contact – a residual current device shall disconnect supply if human being accidentally touches a live conductor.

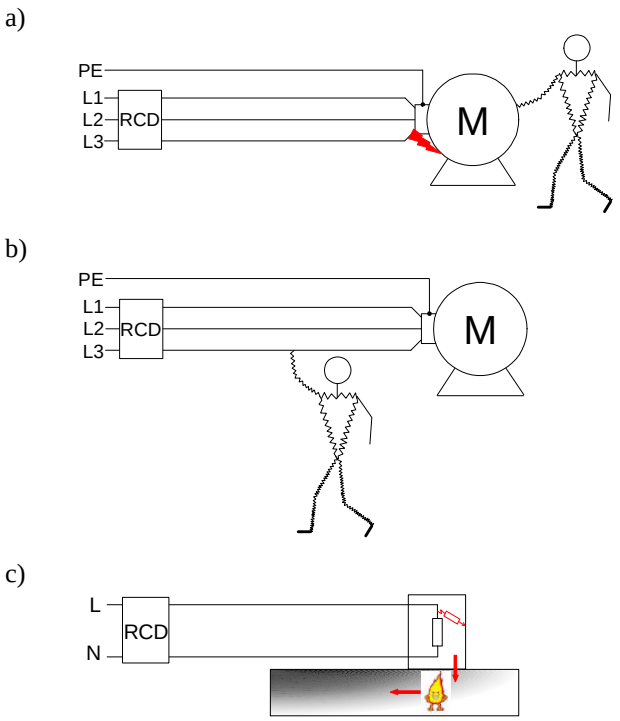

Fig. 1. Residual current device (RCD) provides protection against: a) indirect contact, b) direct contact, c) fire

For a sinusoidal waveform, the residual current devices do not operate if residual current is equal to or less than $0.5I_{\Delta n}$ (residual non-operating current). Their operation is required if residual current equal to or greater than $I_{\Delta n}$ occurs, where $I_{\Delta n}$ is the residual operating current of the residual current device. In order to achieve high degree of protection against electric shock – especially where risk of electrocution is increased (e.g. construction and demolition site installations) – international standard [1] limits the residual operating current of the RCDs. In most cases the residual operating current shall not exceed 30 mA. The operating current for protection against a fire is also limited. Then the residual operating current shall not exceed 300 mA.

Proper operation of residual current devices is guaranteed if earth fault current (residual current) frequency is equal to the rated frequency (usually 50/60 Hz). In circuits with frequency converters the earth fault current can have varying frequency. The higher frequency earth fault current has a negative effect on tripping of the residual current devices. In the next paragraphs the causes of residual current device improper operation under higher frequencies and the method of elimination of this negative effect are presented and discussed.

Operational characteristics of residual current devices

Basic requirements for RCDs operation are contained in standards [2, 3]. A range of tests are there described which have to be carried out for particular types of RCDs and their required response to the test currents. However, program of the test does not cover all residual currents which can occur in practice. Type AC and type A RCDs are not tested under a variable frequency residual current but often used in circuits with frequency converters. The new international standard [3] requires a test within the frequency range up to 1000 Hz but only for type B RCDs.

In order to check the influence of higher frequency residual current, over thirty RCDs with rated operating residual current $I_{\Delta n}$ = 30, 100, 300 and 500 mA were tested. They were type AC, type A and type B undelayed, short-time-delayed and time-delayed (selective) devices. This test was a

continuation of the previous tests and analysis whose results had been presented in [4, 5]. Residual current frequency exceeding 50/60 Hz makes real tripping current of residual current devices rise. In Fig. 2 are presented operational characteristics of the selected type AC and type A residual current devices.

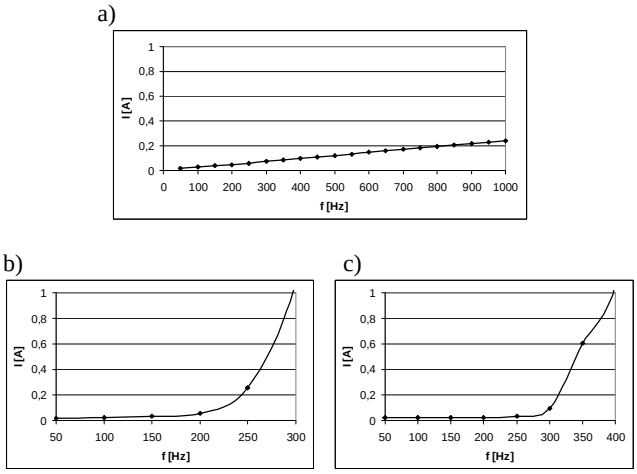

Fig. 2. Tripping current of the selected 30 mA RCDs: a), b) type AC, c) type A. Residual current frequency range during the test: 50÷1000 Hz

In all cases real tripping current increases if residual current frequency rises. Operational characteristics presented in Fig. 2b and Fig. 2c indicate that these residual current devices trip out only if residual current frequency does not exceed 300÷400 Hz. Above the mentioned frequencies these residual devices do not trip out even for residual current equal to a few amperes. It is not acceptable in terms of protection against electric shock and protection against a fire.

Main sources of improper tripping of RCDs

One of the main elements of residual current devices is a current transformer. In the voltage independent protective devices, current transformer has to deliver sufficient power to trip out an electromechanical relay. At the first part of the test the effect of the higher frequency on the current transformer properties was checked.

Induced voltage in the secondary winding of current transformer is described by the following equation:

$$E_s = 4{,}44 \cdot f \cdot N_s \cdot \phi = 4{,}44 \cdot f \cdot N_s \cdot B \cdot s_{Fe} \qquad (1)$$

where f – earth fault current frequency, N_s – number of turns of the secondary winding, F – magnetic field strength, B – magnetic flux density, s_{Fe} – current transformer core cross-section.

The equation (1) shows that if frequency rises then *ceteris paribus* induced secondary voltage should rise in the same way. In practice, secondary voltage may rise only a little. Laboratory tests show that the hysteresis loop of some types of current transformers core is significantly wider for higher frequency (Fig. 3). It is a negative effect, because to achieve the same level of magnetic flux density in the current transformer core for higher frequency, a higher value of earth fault current is necessary.

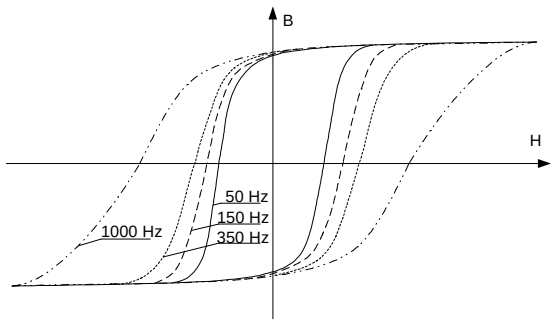

Fig. 3. Hysteresis loops of type AC residual current device current transformer for various frequency primary currents

Fig. 4 presents induced secondary voltage for the example current transformer. If frequency rises twenty times (from 50 Hz to 1000 Hz) the amplitude of the secondary voltage rises less than two times.

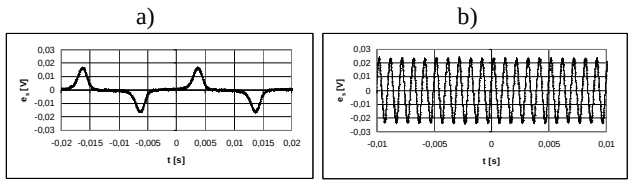

Fig. 4. Induced secondary voltage $e_s(t)$ of current transformer for type AC residual current device of $I_{\Delta n}$ = 300 mA; primary current I_Δ = 300 mA; frequency: a) 50 Hz, b) 1000 Hz

Similar analysis was performed for current transformer of type A RCDs (Fig. 5). For higher frequency the hysteresis loop is not as wide as the previous one. This positively influences the secondary voltage (Fig. 6).

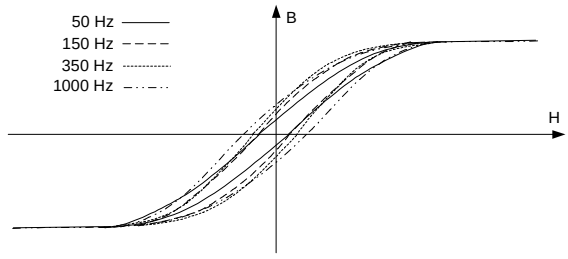

Fig. 5. Hysteresis loops of type A residual current device current transformer for various frequency primary currents

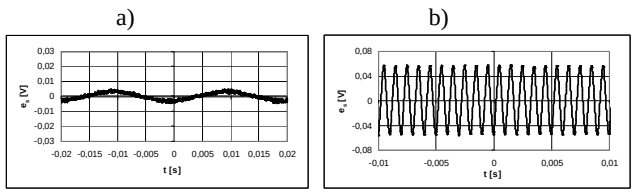

Fig. 6. Induced secondary voltage $e_s(t)$ of current transformer for type A residual current device of $I_{\Delta n}$ = 30 mA; primary current I_Δ = 30 mA; frequency: a) 50 Hz, b) 1000 Hz

If frequency rises twenty times the amplitude of the secondary voltage rises about fifteen times.

Also the higher residual current frequency the higher is the secondary circuit winding and the electromechanical

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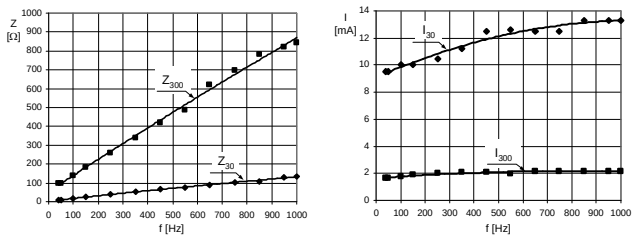
relay impedance, since reactance of these elements $X = 2 \cdot \pi \cdot f L$ rises. Fig. 7a presents variation of impedance of the two electromechanical relays as a function of frequency. In both cases the increase of impedance is strong. In consequence, for higher frequency the secondary current is too small to make the electromechanical relay trip. The value of the secondary current necessary for operating a particular electromechanical relay is presented in Fig. 7b. For both tested RCDs (30 mA and 300 mA) the value of this current rises with frequency only a little.



a) b)

Fig. 7. Variation of the impedance (a) and tripping current (b) of the tested electromechanical relays of: 30 mA RCD (Z_{30}, I_{30}); 300 mA RCD (Z_{300}, I_{300})

Elimination of the negative effect of higher frequency

Taking into account the above analysis, the following solution is proposed. Residual current device which eliminates the negative effect of higher frequency comprises (Fig. 8):

- current transformer with precisely determined magnetic properties for higher frequencies,
- full wave rectifier,
- conventional electromechanical relay.

Parameters of the elements mentioned above should be precisely coordinated.

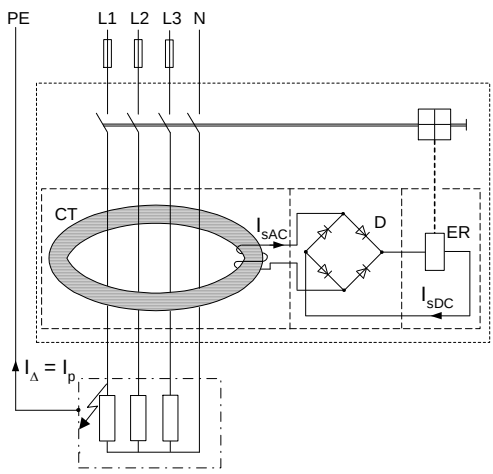


Fig. 8. Simplified diagram of voltage independent RCD with elimination of the negative effect of higher frequency. CT – current transformer with precisely determined magnetic properties, D – full wave rectifier, ER – electromechanical relay

Current transformer should provide secondary voltage rising with frequency in a way which gives stability of the value of current flowing in the electromechanical relay and its reliable tripping. Full wave rectifier prevents electromechanical relay impedance from rising with frequency and gives favourable condition for its tripping in terms of magnetic and dynamic properties. Fig. 9 presents oscillograms of the current in the secondary circuit of current transformer of the prototype RCD of $I_{\Delta n}$ = 300 mA. Amplitude of the $i_{sDC}(t)$ current flowing in the electromechanical relay is almost the same regardless of frequency. For tested frequency equal to 50 Hz the induced secondary voltage is relatively low and only slightly passes the rectifier forward voltage. In consequence the $i_{sDC}(t)$ current has a dead time. For frequency higher than 50 Hz there is no dead time.

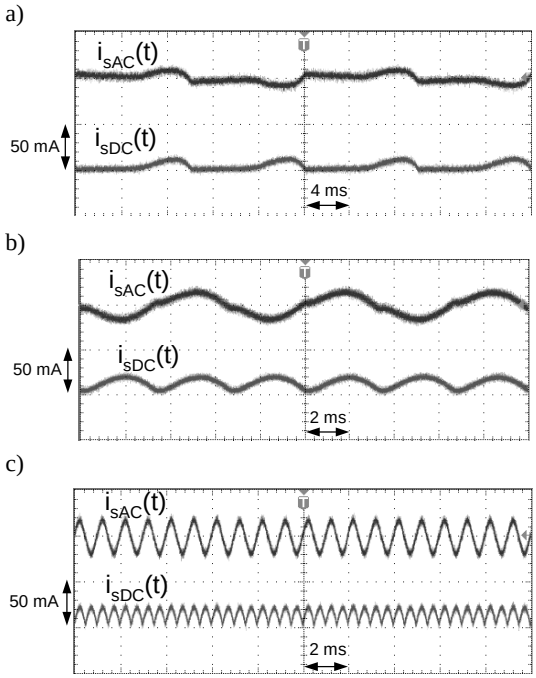


Fig. 9. Current in the secondary circuit of the current transformer. i_{sAC}(t) – a.c. current at the side before the rectifier, i_{sDC}(t) – d.c. current in the electromechanical relay. Residual current frequency: a) 50 Hz, b) 150 Hz, c) 1000 Hz

Operational characteristics of the proposed residual current device of $I_{\Delta n}$ = 300 mA are presented in Fig. 10. There is the I_{AC} line which represents tripping current without rectifier. In such solution tripping current rises with frequency and the operational characteristics are similar to those presented in Fig. 2. However, I_{DC} represents tripping current if rectifier is used. This allows to obtain favourable steady operational characteristics regardless of the higher frequency. Shaded area in Fig. 10 represents the tripping current range required by standards [2, 3] for sinusoidal waveform. The test was performed within frequency range 50÷10 000 Hz and the proposed RCD gave positive effect for the whole range. Requirements of the standards are fulfilled. This solution ensures protection against electric shock and fire if earth fault current frequency varies within a wide range.

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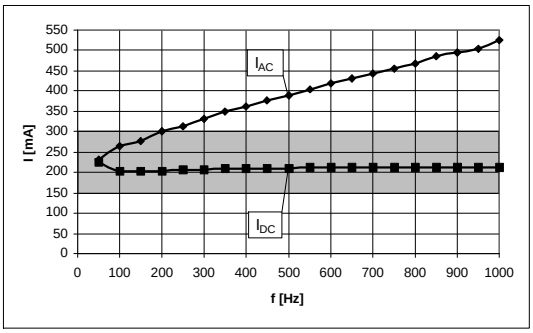
a)



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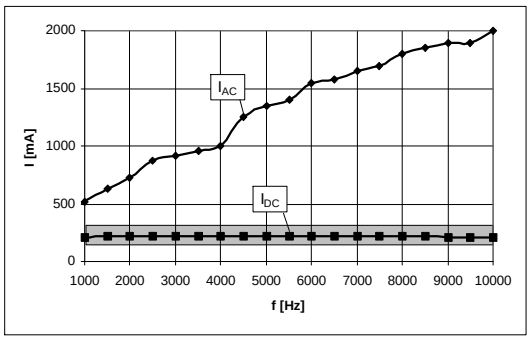

Fig. 10. Tripping current of the proposed RCD of $I_{\Delta n}$ = 300 mA with elimination of the negative effect of higher frequency;
I_{AC} – without rectifier, I_{DC} – with rectifier;
frequency range: a) 50÷1000 Hz, b) 1000÷10 000 Hz

Conclusion

Frequency higher than 50/60 Hz has a negative effect on tripping of the voltage independent residual current devices. Many tested RCDs of $I_{\Delta n}$ = 30 mA do not react to residual current even equal to 5 A if frequency exceeds 400 Hz. It is not acceptable in terms of protection against electric shock and protection against a fire. The proposed residual current device ensures proper detection of earth fault current and operation within a wide frequency range. This solution may be applied to residual current devices intended for circuits with variable frequency of earth fault current.

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2. **EN 61008-1:2005** Residual current operated circuit breakers without integral overcurrent protection for household and similar uses (RCCB's). Part 1. General rules.
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4. **Czapp S.** The Impact of DC Earth Fault Current Shape on Tripping of Residual Current Devices // Electronics and Electrical Engineering. – 2008. – No. 4(84). – P. 9–12.
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Received 2009 02 09

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Earth fault current frequency exceeding 50/60 Hz has a negative effect on tripping of residual current devices. For higher frequency real tripping current of residual current devices moves towards higher values. In some cases the devices may not operate at all. Main sources of the improper tripping of residual current devices for higher earth fault current frequency are discussed. The solution which makes it possible to eliminate the negative effect of higher frequency is presented. Ill. 10, bibl. 5 (in English; summaries in English, Russian and Lithuanian).

С. Цзап. Устранение негативного воздействия утечки высокочастотного тока на устройство защиты // Электроника и электротехника. – Каунас: Технология, 2009. – № 3(91). – С. 85–88.

Ток утечки заземления, частота которого превышает 50/60 Гц, отрицательно влияет на работу от него охраняющих устройств. При более высоких частот увеличивается реальная остсточная нагрузка. В некоторых случаях эти устройства могут не срабатывать. Обсуждаются основные факторы, обуславливающие ненадлежащее срабатывание защитных устройств при высоких частотах тока утечки. Предложен способ устранения отрицательного воздействия высокочастотного тока. Ил. 10, библ. 5 (на английском языке; рефераты на английском, русском и литовском яз.).

S. Czapp. Neigiamo aukštadažnės nuotėkio srovės poveikio apsaugos prietaisams pašalinimas // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2009. – Nr. 3(91). – P. 85–88.

Įžeminimo nuotėkio srovės dažnis, viršijantis 50/60 Hz, neigiamai veikia nuo srovės apsaugančių įtaisų darbą. Esant aukštesniam dažniui, reali liekamoji įtaisų srovė padidėja. Kai kuriais atvejais šie įtaisai gali iš viso nesuveikti. Aptariami pagrindiniai veiksniai, lemiantys netinkamą apsauginių įtaisų veikimą esant didesniam nuotėkio srovės dažniui. Pateikiamas galimas neigiamo aukštojo dažnio srovės poveikio pašalinimo būdas. Il. 10, bibl. 5 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).

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