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Fault Loop Impedance Measurement in Low Voltage Network with Residual Current Devices

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Introduction

According to the standard [1] every low voltage electrical installation shall be verified before being put into service by the user and verified periodically in order to check whether the installation and all its equipment are in satisfactory condition for use. The scope of the initial and periodic verification covers fault loop impedance measurement. Value of loop impedance and selected protective devices influence electric shock and overvoltage hazard [2–4].

The fault loop impedance is measured in circuits with residual current devices (Fig. 1) which are obligatory in selected circuits [4, 5]. Residual current devices cause the problem in fault loop impedance measurement. They trip out during the measurement because the measurement current I_M is the residual current for residual current devices. Proper verification of the installation is then impossible.

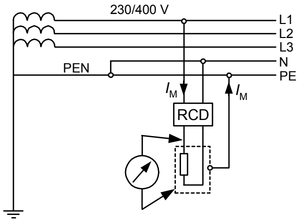


Fig. 1. Fault loop impedance measurement in low voltage TN-system. RCD – residual current device, I_M – measurement current

The methods of earth fault loop impedance measurement [6–11] used in practice are based on the assumption that the tested circuit can be represented by a simplified equivalent circuit as shown in Fig. 2. This circuit comprises a supply sinusoidal voltage source $\underline{E}$, the system equivalent loop impedance $\underline{Z} = R + jX$ and the measurement load impedance $\underline{Z}_0 = R_0 + jX_0$.

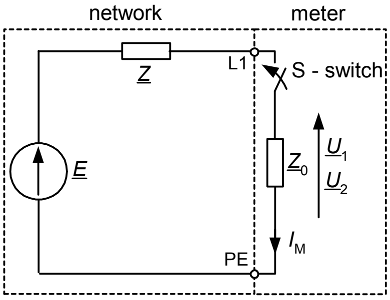


Fig. 2. Equivalent circuit during fault loop impedance measurement

The loop impedance $\underline{Z}$ can be determined by measuring the voltage $\underline{U}_1$ (switch S is opened) and load voltage $\underline{U}_2$ (switch S is closed) between the phase conductor L1 and the protective conductor PE

$$\underline{Z} = \frac{\underline{U}_1 - \underline{U}_2}{\underline{I}_M} = \underline{Z}_0\left(\frac{\underline{U}_1}{\underline{U}_2} - 1\right), \quad (1)$$

here $\underline{U}_1$ – open circuit voltage, $\underline{U}_2$ – load voltage; $\underline{Z}$ – loop impedance; $\underline{Z}_0$ – measurement load impedance, $\underline{I}_M$ – measurement current.

In practice real fault loop impedance Z is measured as a Z_p on the basis of the magnitude of U_1 and U_2 voltages. It provides to the following dependence

$$Z_p = \frac{U_1 - U_2}{I_M} = Z_0\left(\frac{U_1}{U_2} - 1\right). \quad (2)$$

The above assumption gives the measurement error δZ which can be calculated by the following expression

$$\delta Z = \frac{Z_p - Z}{Z} = \frac{\sqrt{1 + \frac{Z}{Z_0} + 2\frac{Z}{Z_0}\cos(\phi - \phi_0) - 1}}{\frac{Z}{Z_0}} - 1, \quad (3)$$

here ϕ – phase angle of the impedance Z; ϕ_0 – phase angle of the impedance Z_0.

Measurement error should not be higher than 30% [12] and depends on the following factors:

- Voltage fluctuation and voltage deviation;
- Transient state when the switch S is closed;
- Voltage distortion;
- Phase angle difference ϕ - ϕ_0;
- Operating loads;
- Value of the measurement current.

For high accuracy of the fault loop impedance measurement it is important to use a meter with respectively high value of measurement current. Fig. 3 presents the effect of the measurement current value on measurement accuracy. The higher is measurement current the higher is measurement accuracy.

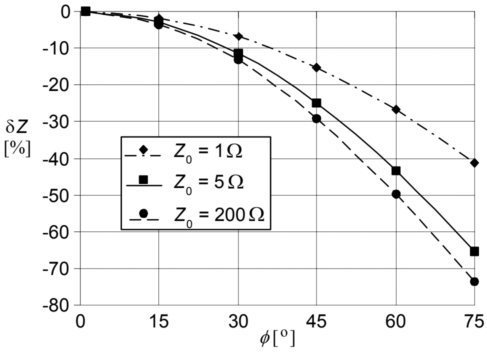


Fig. 3. Fault loop impedance ($Z = 1\ \Omega$) measurement error δZ for various value of the measurement load impedance Z_0: $Z_0 = 1\ \Omega$ ⇒ high measurement current, $Z_0 = 5\ \Omega$ ⇒ medium measurement current, $Z_0 = 200\ \Omega$ ⇒ low measurement current

Testing of the example meters

In order to check the properties of the loop impedance meters which are commonly used in practice a laboratory test was performed. Using a digital oscilloscope a measurement current of the three selected meters (Meter-M1, Meter-M2, Meter-M3) was recorded.

Various fault loop impedance meters provide various types of measurement current shape and measurement time. The most popular are the meters with half-wave current (Fig. 4). Such a meter enables to measure only fault loop resistance. Peak value of the current is equal to about 20 A.

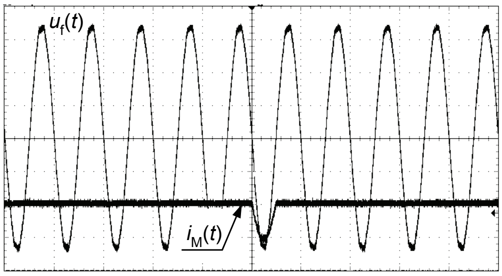


Fig. 4. Oscillogram of the phase voltage $u_f(t)$ and measurement current $i_M(t)$ of the "Meter-M1", scale: time 20 ms/div, voltage 100 V/div, current 20 A/div

Oscillogram in Fig. 5 presents measurement current $i_M(t)$ of the typical loop impedance meter. The current flows within 30 ms. Peak value of the current is equal to about 30 A.

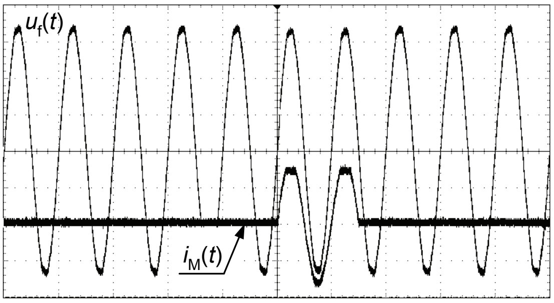
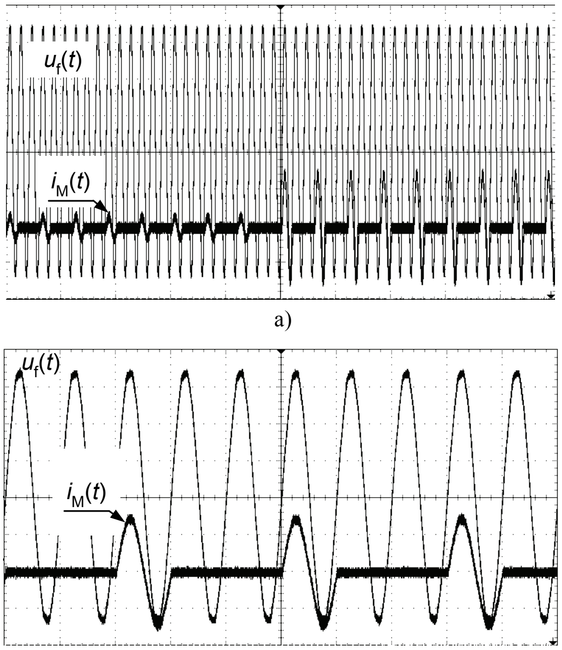


Fig. 5. Oscillogram of the phase voltage $u_f(t)$ and measurement current $i_M(t)$ of the "Meter-M2", scale: time 20 ms/div, voltage 100 V/div, current 20 A/div

Different from the mentioned above is the measurement current $i_M(t)$ presented in Fig. 6. The current flows sequentially and increases with time. The total time of current-flow is about 5 s. The peak value is not higher than 1 A.



a)

b)

Fig. 6. Oscillogram of the phase voltage $u_f(t)$ and measurement current $i_M(t)$ of the "Meter-M3", scale: a) time 100 ms/div, voltage 100 V/div, current 0,5 A/div; b) time 20 ms/div, voltage 100 V/div, current 0,5 A/div

Residual current devices performance and test

Behavior of the residual current devices during the fault loop impedance measurement strictly depends on their parameters and properties of the meter. The most important is their sensitivity to the residual current shape [13]. From this point of view there are three types of residual current devices:

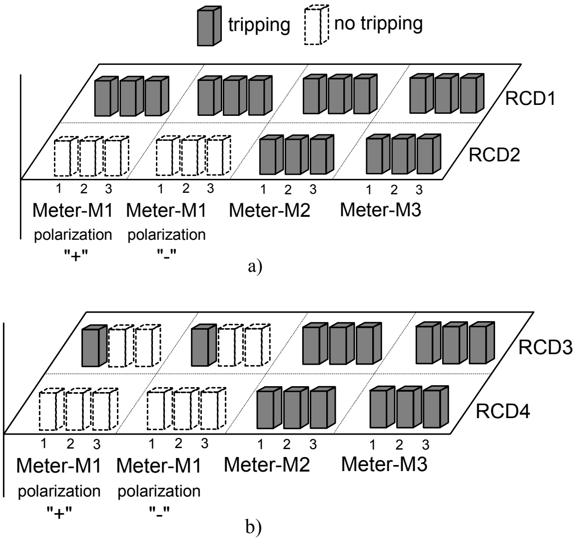
- AC – for residual sinusoidal alternating currents (50/60 Hz);
- A – for residual sinusoidal alternating currents (50/60 Hz) and pulsating direct residual current;
- B – for residual sinusoidal alternating currents up to 1000 Hz, pulsating direct residual current and smooth direct residual current.

A time-delay in operation of the residual current devices is also important. Taking this into account there are three types of RCDs:

- General purpose RCD, without intentional time-delay, without special symbol;
- Short time-delayed RCD (G-type), with a minimum non-actuating time of 10 ms;
- Time-delayed RCD (S-type), with a minimum non-actuating time of 40 ms, to provide discrimination with downstream general purpose or and G-type RCD.

On the base of the analysis of the measurement currents presented in Fig. 4, Fig. 5 and Fig. 6 and properties of residual current devices it is possible to evaluate which method/meter is suitable for circuit with particular type of residual current device.

In the laboratory circuit various residual current devices 30 mA and 300 mA (AC, A, G-type, S-type) were alternately installed and fault loop impedance using the Meter-M1, Meter-M2 and Meter-M3 was measured. Reaction of the residual current devices to the measurement current was recorded. The result of the test is presented in Fig. 7 and Fig. 8. For each residual current device loop impedance was measured three times (column number 1, 2, 3 in Fig. 7 and Fig. 8). Additionally, for the Meter-1 (half-wave current) loop impedance was measured for each polarization: “+” and “-“.



a)

b)

Fig. 7. Reaction of the residual current devices ($I_{\Delta n}$ = 30 mA) to the measurement current: a) RCD1(A), without intentional time-delay; RCD2(A), G-type, b) RCD3(AC), without intentional time-delay, RCD4(AC), G-type

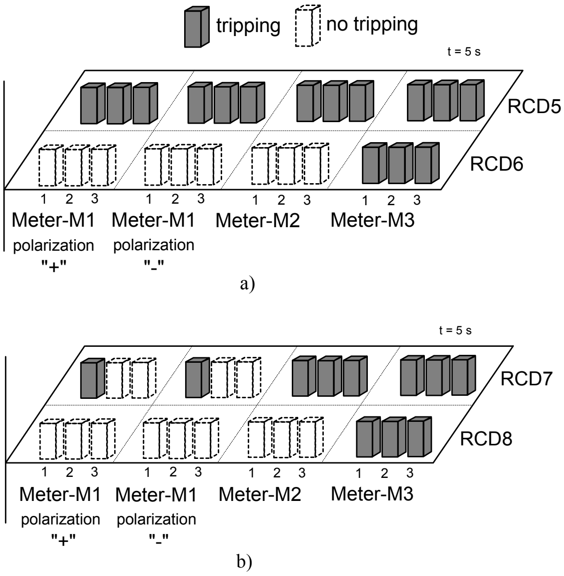
Residual current devices RCD1, RCD5 which are suitable for detection pulsating direct residual current (type A) and have no intentional time-delay, trip out in each consecutive test (grey columns in Fig. 7 and Fig. 8). Such devices make fault loop impedance measurement impossible for all presented above meters.

The immunity to half-wave measurement current is observed for G-type (minimum non actuating time of 10 ms) residual current devices (RCD2, RCD4 – white columns in Fig. 7 and Fig. 8). Fault loop impedance measurement is possible using Meter-M1.

The most favorable attribute, in terms of fault loop impedance measurement, have S-type (minimum non-actuating time of 40 ms) residual current devices (RCD6, RCD8). They are immune to half-wave current and full-wave current (t≤40 ms). Fault loop impedance measurement is possible using Meter-M1 and Meter-M2.

Very interesting is behavior of AC type residual current devices (RCD3, RCD7 – with no intentional time-delay operation) under half-wave measurement current. For each polarization they trip out only during the first test, During the second and the third test, measurement of the loop impedance is possible. This is the effect of saturation of current transformer magnetic core.

Meter-M3 – unfortunately – is not suitable for fault loop impedance measurement in the presence of residual current devices. The time of the measurement is respectively long (a few seconds) and regardless of low value of the measurement current all tested residual current devices tripped out.



a)

b)

Fig. 8. Reaction of the residual current devices ($I_{\Delta n}$ = 300 mA) to the measurement current: a) RCD5(A), without intentional time-delay; RCD6(A), S-type, b) RCD7(AC), without intentional time-delay; RCD8(AC), S-type

Conclusions

Fault loop impedance measurement in circuits with residual current devices is inconvenient. They mainly trip out and the measurement is impossible. It is very important to recognize properties of the installed residual current devices and precisely select proper meter. Currently, in Gdansk University of Technology is developed work on a new fault loop impedance meter (using respectively high measurement current) which enables the measurement without tripping of residual current devices.

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In every low voltage electrical installation initial verification and periodic verification shall be performed. One of the test performed during the verification is fault loop impedance measurement. This measurement enables to verify effectiveness of automatic disconnection of supply which is the most often used means of protection in case of fault. Residual current devices – obligatory in particular circuits – cause the problem in fault loop impedance measurement. They trip out during the measurement and proper verification of the installation is impossible. Detailed analysis of the meters and residual current devices tripping circuits enables to find solution for proper performance of the measurement. The paper concerns the sources of the unwanted tripping of residual current devices during fault loop impedance measurement and indicates solutions for convenient measurement. Ill. 8, bibl. 13 (in English; abstracts in English and Lithuanian).

S. Czapp. Kritinio kilpos impedanso matavimas mažos įtampos tinkle su liekamosios srovės įtaisais // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2012. – Nr. 6(122). – P. 109–112.

Kiekvienos mažos įtampos elektros instaliacijos turi būti atlikta pradinė ir periodinė verifikacija. Vienas iš verifikavimo metu atliekamų testų – kritinio kilpos impedanso matavimas. Šis matavimas leidžia įvertinti automatinio atjungiklio efektyvumą. Matavimo metu jie atsijungia, todėl neįmanoma tinkamai verifikuoti instaliacijos. Analizuojami liekamosios srovės įtaisų nepageidaujamo atsijungimo šaltiniai kritinio kilpos impedanso matavimo metu, pateikiami ir siūlomi patogaus matavimo. Il. 8, bibl. 13 (anglų kalba; santraukos anglų ir lietuvių k.).