

Implementation of new equipment for the laboratory exercises – Testing of low-voltage electrical installations

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Abstract: *This paper presents the new equipment that is used for laboratory exercises in the subject of Electrical installations and lighting at the undergraduate academic and professional studies in the Faculty of Technical Sciences in Čačak. Multifunctional electrical installation safety testers for testing domestic and industrial electrical installations were presented. A demonstration board that provides simulation of different types of faults in electrical installations is also presented. As an illustrative example, the paper presents the procedure and results obtained during the realization of the exercise - Measurement of ground fault loop impedance in TT and TN earthing systems and checking the conditions for automatic disconnection of supply.*

Keywords: *Electrical installations; fault loop impedance; laboratory exercises; testing.*

1. INTRODUCTION

Practical exercises can contribute to a better understanding of theoretical lessons that are studied during classes. Working with the new equipment in laboratories can prepare students for future professional work. For this purpose, new laboratory equipment was acquired in previous years for developing and conducting the laboratory exercises on the subject of *Electrical installations and lighting*. Through the implementation of the project "Development of higher education", the Faculty of Technical Sciences in Čačak (FTS) acquired measuring instruments with additional equipment for testing low-voltage electrical installations. The equipment is used for conducting laboratory exercises on subjects in basic academic (*Electrical installations and lighting, Micro-installations and components*) and basic professional studies (*Electrical installations and lighting*).

Laboratory exercises envisage that students become familiar with the method and procedure of testing low-voltage electrical installations as currently determined by the Rulebook [1] and the SRPS HD 606364-6 standard [2]. Due to the content volume of electrical installations testing, students in the laboratory conduct exercises that were previously discussed in theoretical classes (lecture and calculation exercises). The laboratory exercises include the following types of testing: Continuity (resistance measurement) of the protective conductor; Insulation resistance measurement; Fault loop impedance measurement

and prospective fault current determination; Residual current protection devices (RCD) testing. In general, it is possible to realize exercises that can be simulated on the demonstration board, listed in [3]. Before exercises, students are introduced to the possibilities of instruments for electrical installations testing and additional equipment. This is done for the purpose of safe and efficient work in the laboratory.

In continuation of this paper, the second chapter describes the new equipment that students use for laboratory exercises: two multifunctional instruments for low-voltage electrical installations testing (chapter 2.1) and demonstration board for error simulation in electrical installations (chapter 2.2). In the third chapter, exercises examples of fault loop impedance measurement with verifying the effectiveness of installed overcurrent or residual current protective device in TT (chapter 3.1) and TN (chapter 3.2) systems are presented.

2. EQUIPMENT FOR THE LABORATORY EXERCISES

2.1 Multifunctional measuring instruments for electrical installation safety testing

A special type of multifunctional measuring instruments are used for low-voltage electrical installations safety testing. For conducting the laboratory exercises, students at FTS use two instruments manufactured by *Metrel*: MI 3152 *EurotestXC* (Figure 1) and MI 3155 *EurotestXD* (Figure 2) with their additional accessories (*EU*

set). These instruments have, in addition to others, the following functions [4,5]:

- Insulation resistance measurement up to 1 kV;
- Testing the continuity (resistance) of the protective conductor;
- Testing residual current devices;
- Fault loop impedance measurement and prospective fault current determination;
- Earthing resistance measurement;
- Earth resistivity measurement;
- Voltage and frequency measurement;
- Active, reactive and apparent power and voltage and current harmonics measurement.



Figure 1. Multifunctional electrical installation tester Metrel MI 3152 EurotestXC.



Figure 2. Multifunctional electrical installation tester Metrel MI 3155 EurotestXD.

Instruments MI 3152 and MI 3155 have additional accessories (*EU set*) which contain:

- Earth set, 3-wire, 20 m;
- Single phase plug commander, 1.5 m;
- 3-wire test lead, 3 x 1.5 m;
- 4-wire test lead, 4 x 1.5 m (only MI 3155);
- 2.5 kV test lead, 2 x 1.5 m (only MI 3155);
- Test probe, 4 pcs (black, blue, green, red);
- Crocodile clip, 6 pcs;
- Current clamp 1000:1;
- Current clamp (low range, leakage);
- RS232-PS/2 cable and USB cable;
- Li-ion battery pack, 7.2 V, 4400 mAh and power supply adapter 12 V, 3 A.

2.2 Demonstration board for simulation in electrical installations

The demonstration board *Metrel MA 2067* is used to simulate different conditions in low-voltage electrical installations. This board is very practical to show the application of electrical installations

safety testers in laboratory conditions. The front panel of demonstration board is shown in Figure 3-a. On the board, it is possible to simulate several different errors in the three major types of earthing systems: TT, TN and IT system. This board is capable of measuring and testing [3]: Resistance of electrical installation insulation; Continuity (resistance) of the protective conductor; Earth resistance; Specific earth resistance; Line fault loop impedance (L-N, L-L); Ground fault loop impedance (L-PE); Disconnection times and trip-out currents of RCDs; Contact voltage; Voltage and frequency, etc. The error condition is realized by turning on the control switches located on the control part of the board (Figure 3-b). With these control switches, it is possible to demonstrate 19 different errors: Line impedance (switches S1-S3); Resistance of protective (PE) conductors (switches S4-S11); Earthing resistance (switches S12, S13); Soil resistivity (switches S14, S15) and Insulation resistance (switches S16-S22). The simulated error in the electrical installation, i.e. the position of the control switches, can be physically concealed (locked) so that the students can't know the type and location of the error.

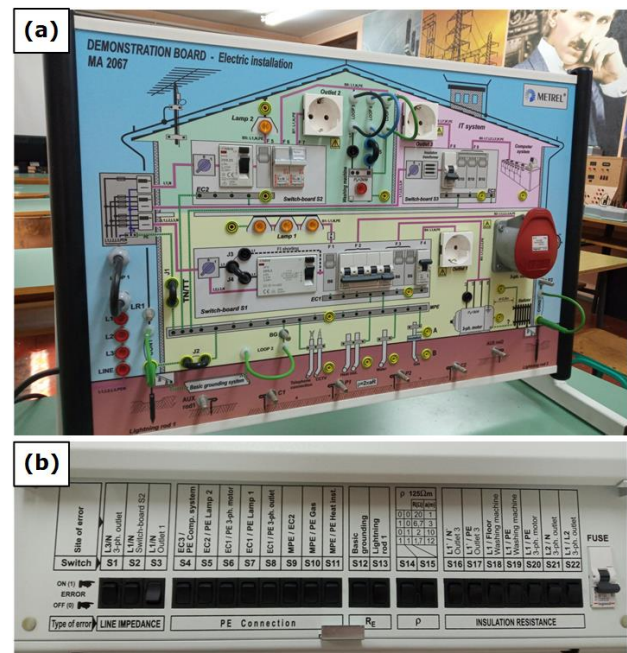


Figure 3. (a) Front panel and (b) command part of demonstration board.

3. EXAMPLES OF LABORATORY EXERCISES - FAULT LOOP IMPEDANCE MEASUREMENT

Examples of the laboratory exercises that students perform are presented in this chapter. The first part of the exercises shows the method of fault loop impedance measurement (*Z-loop*) and the fulfilment of the conditions for protection in the TT system, while the second part describes the same thing but in the TN system. The measurement of the fault loop impedance is performed in order to check the efficiency of the applied protective

overcurrent device (circuit breaker/fuse) or RCD. After the loop impedance measurement, the prospective fault current and contact voltage are determined. Then, the prospective fault current (I_{psc}) is compared with the current for the rated disconnection time of the circuit breaker/fuse (I_a) or with the rated residual operating current of RCD ($I_{\Delta n}$). The exercises were performed using the equipment shown in Figure 4.

In a TT system, the fault loop impedance is determined as [6]

$$\underline{Z}_{loop,TT} = \underline{Z}_L + \underline{Z}_{PE} + R_{Eh} + R_{Ed} + \underline{Z}_T, \quad (1)$$

where \underline{Z}_L is phase conductors impedance, \underline{Z}_{PE} is the protective conductors impedance, R_{Eh} is the earthing resistance of installation, R_{Ed} is the earthing resistance of source (distribution point) and \underline{Z}_T is the power transformer secondary impedance. In a TN system, the fault loop impedance is determined as [6]

$$\underline{Z}_{loop,TN} = \underline{Z}_L + \underline{Z}_{PE} + \underline{Z}_T. \quad (2)$$

In the TT system, overcurrent protection is effective if [6]

$$Z_{loop,TT} \cdot I_a \leq U_0, \quad (3)$$

while the protection against excessive touch voltage is effective if [6-9]

$$R_A \cdot I_a \leq U_C \quad (4)$$

or [6]

$$Z_{loop,TT} \leq \frac{U_C}{I_{\Delta n}} = \frac{50 \text{ V}}{I_{\Delta n}}, \quad (5)$$

where I_a is the current causing automatic cut-off of protective device within the required time, U_0 is the system voltage to earth ($U_0 = U_{L-PE} = 230 \text{ V}$), $R_A = R_{Eh} + R_{PE}$ is resistance of protective earthing (earth probe and PE wiring resistance), U_C is the limit contact voltage on exposed conductive parts and $I_{\Delta n}$ is the residual operating current of RCD. In the TT system, the RCD is most often to use for protection, and then the operating current is rated residual operating current of RCD ($I_a = I_{\Delta n}$) [6,9]. In TN system, conditions for protection with automatic disconnection of supply is [6-9]

$$Z_{loop,TN} \cdot I_a \leq U_0. \quad (6)$$

Disconnection times for final circuits ($U_0 = 230 \text{ V}$) in TT and TN systems are 0.2 s and 0.4 s, respectively [6,8].

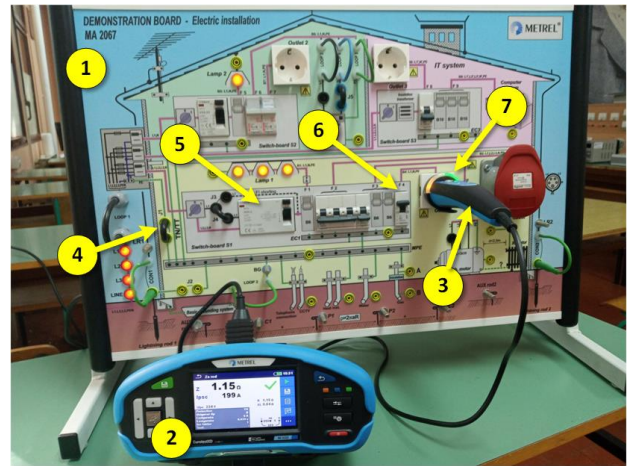


Figure 4. Equipment used for fault loop impedance measurement: **1** – demonstration board, **2** – Metrel MI 3155 tester, **3** – single phase plug commander, **4** – jumper J1 (for TT or TN system set), **5** – RCD 25A/0.3A for protection of socket outlet 1, **6** – miniature current breaker B 6A for protection of socket outlet 1, **7** – socket outlet 1.

3.1 Example of fault loop impedance measurement in TT system

The Figure 5 shows the results of fault loop impedance measurement on outlet 1 in the TT system (jumper J1 removed). Since the circuit of this outlet is protected by RCD $I_{\Delta n} = 0.3 \text{ A}$, the maximum permissible value of the fault loop impedance determined by expression (5) is

$$Z_{loop,TT,max} = \frac{50}{0.3} = 166.7 \Omega.$$

In the case without error, the measured value of the loop impedance is $Z_{loop,TT(a)} = 11.5 \Omega < 166.7 \Omega$ and the condition given by expression (5) is satisfied (Figure 5-a). With error simulation by increasing the phase conductor impedance (in practice, increasing the length or decreasing the cross-section area of the conductor), the measured value of the loop impedance is $Z_{loop,TT(b)} = 21.4 \Omega < 166.7 \Omega$, and the condition given by expression (5) is satisfied in this case as well (Figure 5-b). If error is simulated by increasing the earthing resistance of installation, the measured value of the loop impedance is $Z_{loop,TT(c)} = 252 \Omega > 166.7 \Omega$, and the condition given by expression (5) is not satisfied (Figure 5-c). In this case, the high value of earthing resistance contributes to the appearance of high contact voltage on the exposed metal parts connected to the PE conductor. Specifically, after measuring the loop impedance with error ($Z_{loop,TT(c)} = 252 \Omega$), the calculated prospective fault current has a value

$$I_{psc,TT(c)} = \frac{U_0}{Z_{loop,TT(c)}} = \frac{230}{252} = 0.91 \text{ A}.$$

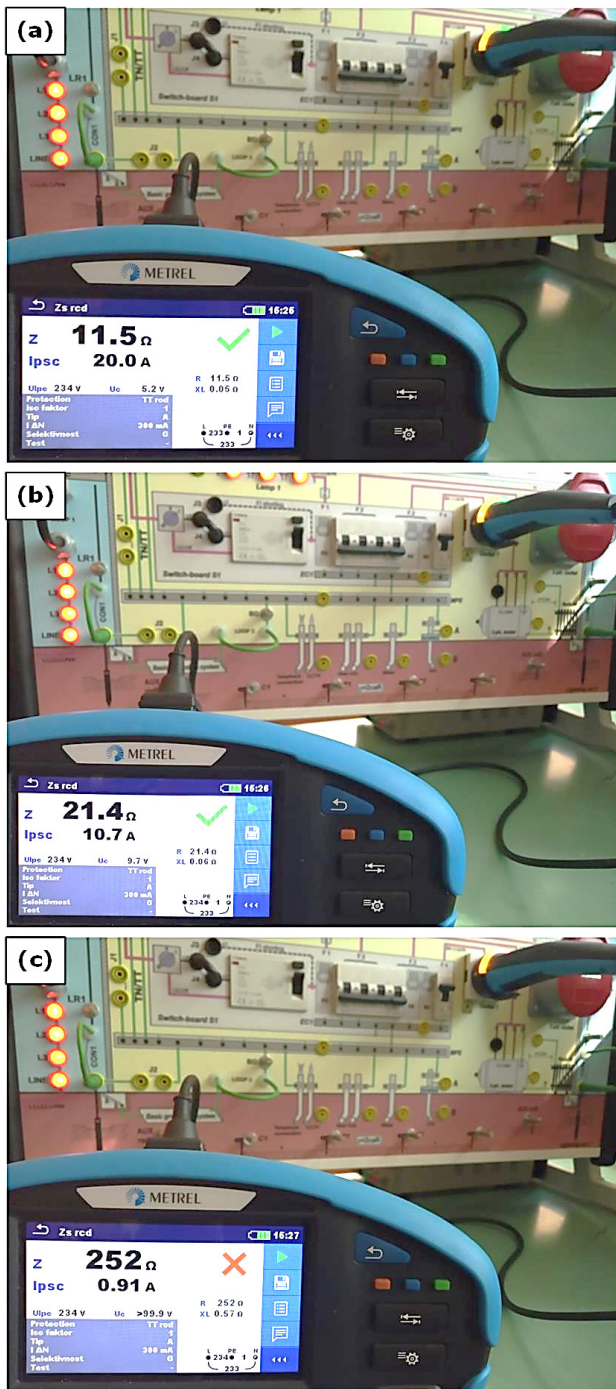


Figure 5. Results of fault loop impedance measurement at the socket outlet 1 in TT system for case: (a) without error ($Z_{loop}=11.5 \Omega$); (b) with error - caused by phase conductor impedance increase ($Z_{loop}=21.4 \Omega$); (c) with error - caused by installation earthing resistance increase ($Z_{loop}=252 \Omega$).

Although prospective fault current is higher than the rated residual operating current of RCD, it creates an unacceptably high value of the contact voltage

$$U_{C(c)} \approx R_{A(c)} \cdot I_{psc,TT(c)} = 250 \cdot 0.91 = 227.5 \text{ V,}$$

where $R_{Eh(c)} \approx 250 \Omega$ is the resistance of protective earthing with simulated error.

If a circuit breaker type B 6A were to be used to protect the socket outlet 1, there would be no condition for protection for all three analyzed cases. Then the condition from expression (3) is not satisfied because

$$Z_{loop,TT(a)} = 11.4 \Omega > \frac{U_0}{I_{a(B6A)}} = \frac{230}{30} = 7.67 \Omega.$$

A scheme of electrical installation on the demonstration board for fault loop impedance measurement at socket outlet 1 is shown in Figure 6. In the scheme, the red solid arrows show the test current flow during the loop impedance measurement in the TT system. The red dashed arrows show the test current flow during the loop impedance measurement in the TN system.

3.2 Example of fault loop impedance measurement in TN system

Figure 7 shows the results of fault loop impedance measurement at socket outlet 1 in the TN earthing system. To select TN system jumper J1 must be set. In the TN system, the circuit of socket outlet 1 is protected by a circuit breaker with rated current $I_{n0} = 6 \text{ A}$ and B tripping characteristic (B 6A). For this type of circuit breaker, the trip-out current has a value

$$I_a = 5 \cdot I_{n0} = 30 \text{ A.}$$

The maximum value of the fault loop impedance in the case of using the overcurrent protective device (circuit breaker B 6A) determined by the expression (6) is

$$Z_{loop,TN,max} = \frac{U_0}{I_a} = \frac{230}{30} = 7.67 \Omega.$$

For the fault loop impedance measurement in the TN earthing system, the "Zs rsd" option must be set. These settings take into account the existence of RCD in electrical installation. Also, for the type of protection system in the instrument settings "TN" was selected. In that case, only the overcurrent protection (current breaker with B, C and D trip characteristics or fuse) is active for checking. An example of fault loop impedance measurement on the board in a TN system without error is shown in Figure 7-a. Then, the measured impedance is $Z_{loop,TN(a)} = 1.14 \Omega < 7.67 \Omega$, so condition (6) is satisfied. With error simulation by increasing the phase conductor impedance (in practice, increasing the length or decreasing the cross-section area of a conductor), the measured value of the loop impedance is $Z_{loop,TN(b)} = 11.2 \Omega > 7.67 \Omega$, and the condition given by expression (6) is not satisfied (Figure 7-b).

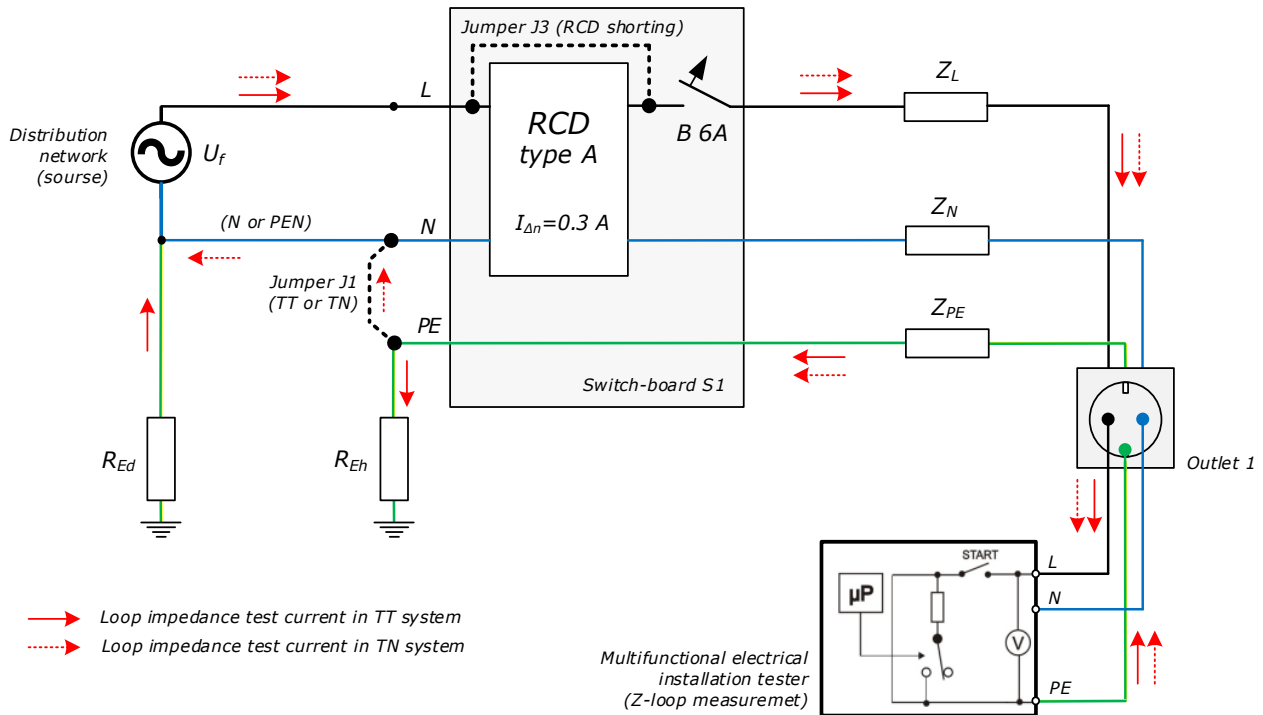


Figure 6. Principle of loop impedance measurement on the demonstration board (socket outlet 1) in TT and TN system.

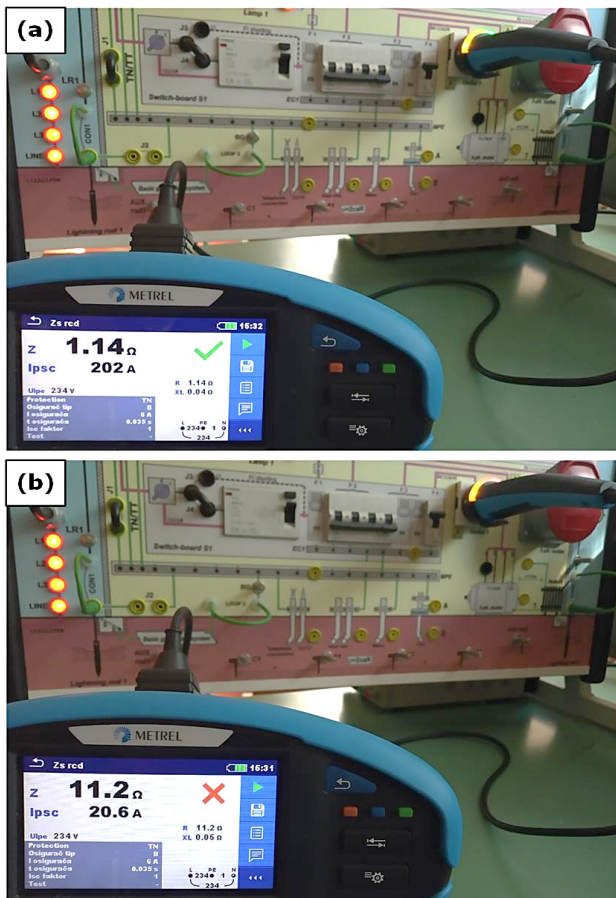


Figure 7. Results of fault loop impedance measurement at the socket outlet 1 in TN system for case: (b) with error - caused by phase conductor impedance increase ($Z_{loop}=11.2 \Omega$).

It should be noted that for this type of fault loop impedance measurement, it is necessary to use the "Zs rsd" option, because there is a RCD for the protection circuit of socket outlet 1. If this option is not used, the RCD would trip-out unnecessarily and measurement would not be successful. The reason for this unwanted tripping is the existence of a test current which becomes a differential current that causes RCD to react (red dashed arrows in Figure 6).

4. CONCLUSION

The implementation of laboratory exercises for testing low-voltage electrical installations contributes to a better understanding of the theoretical content that students learn in classes (in lectures and calculation exercises). During laboratory exercises, students have the opportunity to gain experience in working with new equipment for electrical installations safety testing. It is especially important to explain protective measures against electric shocks. That is one of the reasons why the paper presents examples of fault loop impedance measurement in TT and TN earthing systems. In the future, an increase in the number of exercises will be considered, as well as worktime student spend in the laboratory. All of this is aimed at gaining students experience in working with new measuring equipment and more practical knowledge.

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