Lessons from a Loop Impedance Test at the Inspection of Electrical Installation

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***Abstract* — During the measurement of the loop impedance performed with 230 V the electronic supervisory system of the facility, i.e. a mall went wrong. The direct cause was that, the protective earth (PE) conductor was cut and this fact was not detected before the loop impedance measurement. The damage could have been prevented with either of two measures: (1) By performing the continuity test of the PE conductor before the loop impedance measurement. In spite of the belief of many electricians the instrument widely used for this purpose does not perform automatically a continuity test before the measurement. (2) By a correct connection of the PE conductor to the electronic devices. Developers of the electronic devices used the PE as the third conductor of the CAN data transmission line, thus not achieving the basic insulation between PE and the electronic operating with extreme low voltage.**

I. Introduction

In a practical case, during the authentic supervision of electric shock protection of the electrical system in a shopping mall, a loop impedance measurement was performed during live operation. At the same time the most of electronic units of the facility building management system was breaking down. The associate team of Department of Electrical Networks, Faculty of Engineering and Information Technology, University of Pécs (PTE MIK) have been requested to examine the major damage of electronic control system of the building facility management system.

The case study serves many lessons for us too. The immediate cause of the system failure was the lack of PE protective conductor in one of the electrical cabinets and the lack of preliminary findings of this fact.

The rather huge damage could have been avoided in two ways: (1) the completion of test of protective earth (PE) continuity before the loop impedance measurement; (2) a professional wiring of PE in the electronic units.

II. The Prior Situation

At the inspection of electric shock protection, performed during normal building operation, a widely used measuring device was applied, according to the applicable standard measurement method. According to the relevant standards [1], [2] in this case the loop impedance measurement must be performed by testing of continuity of the protective earth system. In examined case the PE conductor in one of the electrical cabinets in the building was unfortunately broken as shown in *Figure 1*, but the continuity test of PE conductor was not performed prior to the standard loop impedance measurement.

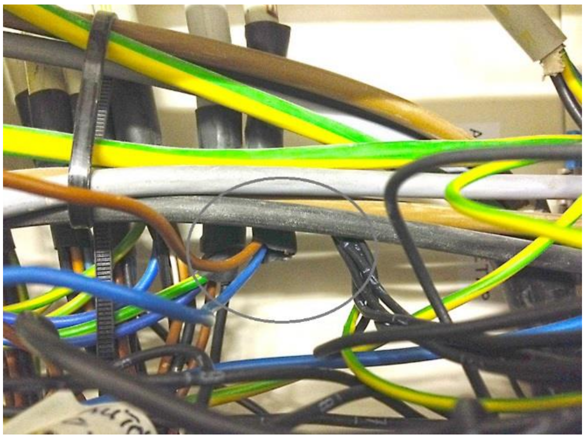

Figure 1

PE conductor is missing (cut)

The green-yellow PE conductor is missing in one of the rack cabinets as marked in *Figure 1*. The other end of this PE conductor is connected properly to the correct point in the adjacent electrical cabinet but, due to the broken PE conductor, the ground potential cannot be measured at any point of this rack cabinet.

As the expert, carrying out the measurements, stated the device automatically performs testing of protective conductor continuity prior to the loop impedance measurement and the absence of continuity in the loop impedance measurement is prohibited.

However, in fact the instrument has enabled and performed the loop impedance test despite the lack of PE conductor and the measuring current, being set over 10 A even for short, has destroyed the electronic units connected directly to PE conductor.

III. Properties of the Measuring Instrument

The instrument used for test is **a** popular, authorized and excellent product. Nowhere mentioned in its handbook [3] that any kind of continuity test on PE conductor is performed prior to the standard loop impedance test. As manual says, prior to the loop impedance measurement the only test with the help of phase conductor (L) if the potential difference between the PE conductor and the (grounded) tester person exceeds the allowed contact voltage as it would be occurred at hazardous reversed connection of L and PE conductors. If so, it stops the test with error message of ‘Hazardous voltage on PE’.

According to the manual [3] the PE continuity test is allowed with this instrument at a low voltage (6 volts) when the system is out of operation, i.e. switched off. The internal circuits and measuring methods of the instrument are not published by the manufacturer. The method of the loop impedance test is supposed from the control tests performed in laboratory of PTE MIK and is shown in the *Figure 2* Prior to loop impedance test the instrument operator person touches the contacts under the START button.

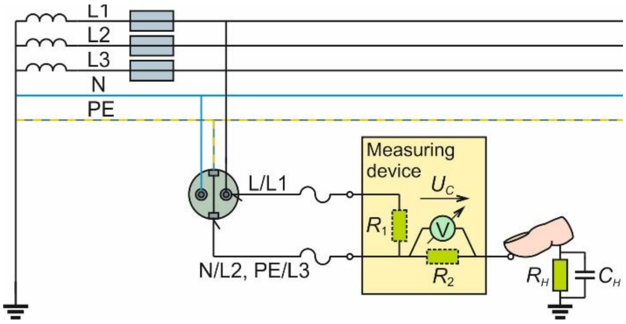

Figure 2

Schematic circuit of the preliminary tests

The resistance R_H on *Figure 2* represents the resistance between the floor and the shoes of the instrument operator and the capacitance C_H is the capacitance of a man with an average value of 150 pF.

During laboratory tests, approximately 80 volts have been measured between the contact terminals of the instrument and grounded PE. Regarding to the 1.5 MΩ input resistance of the analog voltmeter the assumed amount of the R_1 and R_2 resistances is 3 MΩ while the instrument measures the U_C contact voltage.

For loop impedance test the instrument is connected to L and PE conductors. The supposed preliminary test circuit is shown in *Figure 2*. If PE is not connected to any other potential (even through an electronic circuit) then the instrument displays the dangerous voltage and prohibits further measurements, like it does at L and PE exchange.

IV. THE FAILURE PROCESS

The building management system components i.e. the electronic control unit (PLC) and other electronic devices are located in electronic cabinets all over the building. The control units with separate power supplies have shielded twisted pair connection using CANopen protocol. The shield is connected to protective earth (PE) at a single point in a building in one electronic cabinet. CAN_H and CAN_L pins of communication port of each controller are connected parallel to twisted pair that is terminated in both end with $R_T = 120\,\Omega$ terminators. CAN_GND pin of communication port of each controller is connected to local PE points as ‘reference ground’ in each electronic cabinet as shown in *Figure 3*.

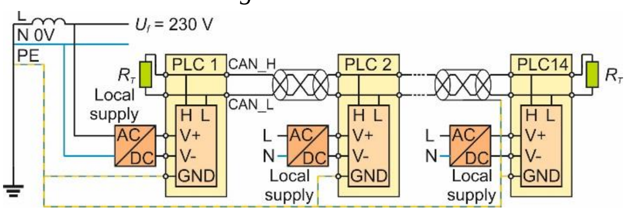

Figure 3

Connection of PE to electronic units

Laboratory control tests have proved if PE conductor is broken that is connected i.e. to ‘PLC 1’ the instrument cannot detect dangerous touch voltage and allows the loop impedance measurement. This happened also during the supervision of electric shock protection. According to the instrument's guide the loop impedance measurement is performed as shown in *Figure 4*. The instrument connects R_L=12 Ω resistor to L and N pins for duration of 10 ms and measures the voltage on it. The fault circuit with the known parameters is shown in *Figure 5*.

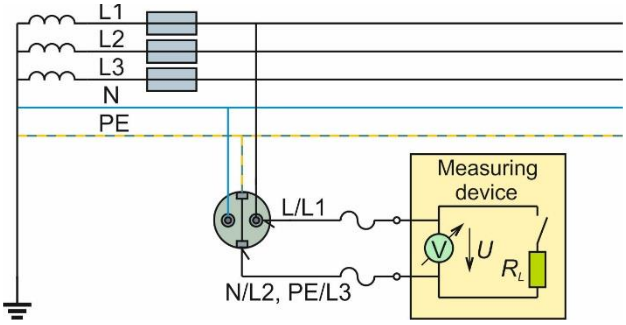

Figure 4

Circuit for the loop impedance measurement

For loop impedance test the measuring instrument is connected to the L phase conductor and to the (broken) PE conductor. So, the broken PE is connected to L phase through R_L = 12 Ω causing *U’* voltage between CAN_GND and CAN_L of PLC 1 controller and causing *U’’* between CAN_GND and CAN_L pins of the other parallel connected controllers. Because of the high number of parallel-connected electronics, at least for the first moments, *U’* is much larger than *U’’*.

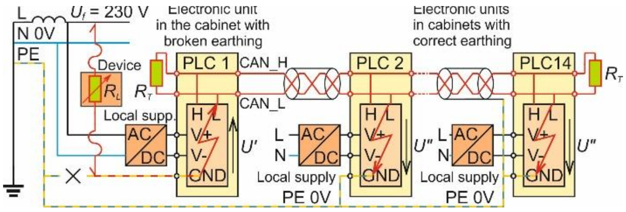

Figure 5

The fault circuit

Initially measuring current, determined by the 12 Ω resistance plus equivalent value of input resistances of the communication ports, flowed through the electronics to the right connected PE points in other electrical cabinets. Since the entire measuring current flowed through the PLC 1 electronics it was overloaded at first.

As result, the PN junction(s) were pierced and the increased voltage on CAN signal lines has damaged the other electronics (or part of its) causing overload current in their PN junctions (in opposite direction). The entire process cannot be reconstructed exactly.

V. THE NEED OF CONTINUITY TEST OF PE CONDUCTORS

How the damage of the electronics with a value of several million forints could have been avoided? First, by testing the continuity of PE conductor. Many believe that the instrument itself performs the PE continuity test prior to loop impedance test which is not stated in the instrument's manual and, according to the response we received from the manufacturer, this does not happen. This fact has been confirmed by the examined case itself. The continuity test of PE conductor prior to the loop impedance test is required by the relevant standard because of the potential rise of the PE conductor due to measurement at a low valued resistor would cause electric shock touching any device connected to PE. The potential conditions are shown in *Figure 6*, interpreting the loop impedance test in case of broken PE conductor.

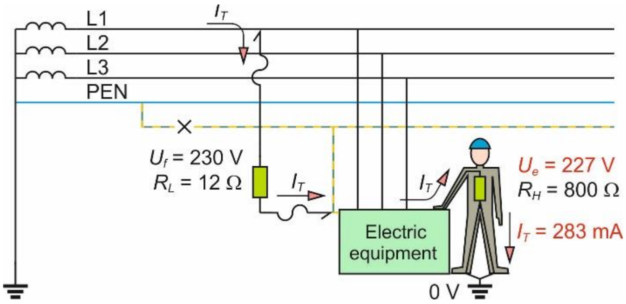

Figure 6

Electric potentials at loop impedance test in case of broken PE conductor

In case of broken PE, according to the voltage division with the human impedance of R_H = 800 Ω (that is the worst case), the contact potential is

$$U_e = U\frac{R_H}{R_L+R_H} = 230\frac{800}{12+800} = 226{,}6\ \text{V} \qquad (1)$$

This potential is far above the allowed maximum contact potential and the person may suffer life-threatening electrical shock.

According to MSZ 4851 / 3-1989 standard [1] the continuity of the PE conductor can be checked by phase voltage using two-pole voltage indicator (test lamp). The two series-connected, 25-watt-bulb resistance can be calculated as

$$R_{pl} = 2\frac{U^2}{P_{pl}} = \frac{2\cdot 230^2}{25} = 4232\ \Omega \qquad (2)$$

which is greater than the resistances used by the measuring instrument in loop impedance test by orders of magnitude. The potential conditions are shown in *Figure 7*. The contact voltage in this case

$$U'_{é} = U\frac{R_H}{R_{pl}+R_H} = 230\frac{800}{4232+800} = 36{,}6\ \text{V} \qquad (3)$$

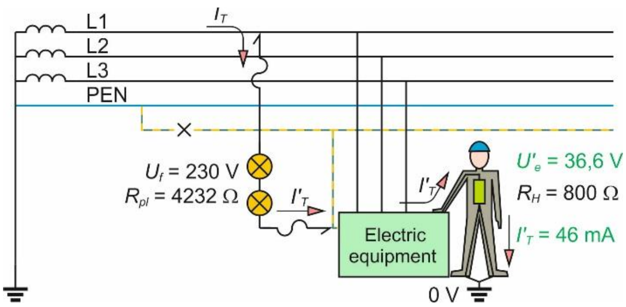

Figure 7

Potential conditions at PE continuity test

The contact voltage is less than its allowed maximum. Although, if R_H resistance is greater than 800 Ω the contact voltage increases, but the current through the human body falls into the range of non-life-threatening zone. This reasonable series resistance, applied in the PE continuity test, would probably have been protected the sensitive electronics against damage.

VI. THE PROPER USE OF PROTECTIVE CONDUCTOR

Damage could have been prevented by the thoughtful and professional connections of communication cables and the PE conductor, as well. The MSZ HD 60364-5-54 [4] standard does not recommend the use of PE wire for current conducting in case of normal (error-free) operating conditions. In case of optimal solution the galvanic connection between signal lines of the electronic circuit and the PE conductor would be eliminated. According to the official resolution requested from the shock protection working committees [5] the connection of the PE conductor was wrong in this case. It should have been connected to each housing of electronic device.

CANopen setup references [6] suggest proper connections to be applied in circuit like in *Figure 8*. The simplest implementation of a three-wire balanced signal connection is that the twisted pair cable is connected to CAN_H and CAN_L terminals and the shielding is connected to CAN_GND as "reference ground". For this case CAN_GND could be marked as CAN_S (shield) and CAN_S must be connected to PE in a single point only! As an enhanced solution, the manufacturers offer five-wire CAN cable also, that contains a twisted pair for CAN_H and CAN_L lines, the other twisted pair is for CAN _+ and CAN_- (+ and -12V supply voltage) and the fifth separate wire within the shielding is for CAN_GND reference ground.

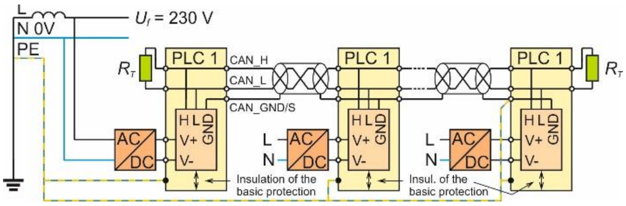

Figure 8

Proper connections of CANopen lines and PE

As shown in Figure 8 the shielding connection to each controller does not occur ground loop because the shield is connected to PE in a single point while insulation protection is available between each signal line, ground and PE. The PE conductor is connected to the electronic unit at its metal housing. In this case the circuit protects the electronics even if the loop impedance test is performed at the broken PE condition i.e. the phase voltage is connected to PE through a small R_L resistor, as shown in Figure 9.

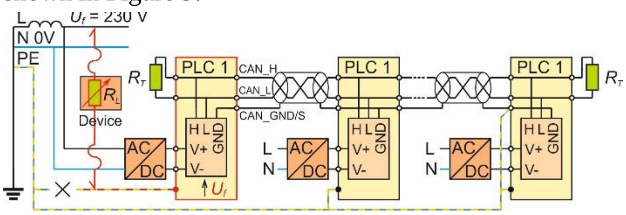

Figure 9

The affect of broken PE in case of proper CAN bus connection

In case of testing the loop impedance at electrical cabinet of PLC 1 with its metal housing connected to the broken PE conductor the housing will be on U_f phase voltage, but properly insulated from the ground potential of CAN_GND wire. So that damage of electronics could be avoided even if the PE continuity test, prior to the loop impedance test is omitted. In this case the preliminary internal test (applying the instrument) would detect dangerous voltage on the PE conductor and so the loop impedance measurement would be disabled.

Other literature dealing with signal transmission [7] suggests also the single common point of the signal ground (CAN_GND) and the protective ground (PE) at one location (one common ground) but for longer signal lines it is recommended to connect each local device CAN_GND signal ground to local PE point through 100 Ω resistor. If the equivalent impedance of signal ground wire to the common grounding is lower at least one order of magnitude than the 100 Ω, the 12 V electronics cannot be damaged even in case of a broken PE connected to either line voltage.

VII. Conclusion

The lessons learned from the examined practical case would be the followings.

1. Prior to the loop impedance measurement, the separate continuity test of the PE conductor always has to be performed, according to the referred standard specification.
2. The continuity test of the PE conductor is not performed automatically by the instrument, commonly used for the standard supervision of electric shock protection.
3. The PE conductor should be used according to its purpose only.
4. The PE conductor should be connected to the metal housing of the electronic device.
5. The PE conductor should not be in galvanic connection with any part of the electronic circuits.

VIII. References

[1] MSZ 4851/3-1989: Érintésvédelmi vizsgálati módszerek. Védővezetős érintésvédelmi módok mérési módszerei *(Hungarian standard on protection against electric shock)*.

[2] MSZ HD 60364-6:2007: Low voltage electric equipment. Part 6: Tests. *(Hungarian version of the harmonized document)*

[3] Measurement on electric installations in theory and practice, Instruction Manual, Code No. 20 750 664, METREL.

[4] MSZ HD 60364-5-54:2012: Low voltage electric equipment. Part 5-54: A villamos szerkezetek kiválasztása és szerelése. Earthing equipment and protective conductors. *(Hungarian version of the harmonized document)*

[5] Memo on the meeting of the Working Committee on Proteciton against electric shock on 2016.04.06-i *(in Hungarian)*.

[6] CANopen Hardware Setup Manual, Schneider Electric, 04/2009.

[7] RS-422 and RS-485 Application Note, B & B Electronics Manufacturing Company, 2006.