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IRREGULARITIES IN CONNECTION AND EXECUTION OF LOW-VOLTAGE ELECTRICAL INSTALLATIONS

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Abstract: This paper aims to address the irregularities that arise during the connection and execution of low-voltage (LV) electrical installations, with a particular focus on the challenges associated with overhead connections for household installations to the LV network. The connection of residential buildings, typically performed using underground cables, and industrial facilities, which often include dedicated transformer stations (TS), present fewer complications. However, a significant concern is the frequent current overload of cables and conductors in low-voltage systems.

Another critical issue lies in the misalignment between the national legal framework and the European standards adopted from the European Union. Despite their formal adoption, these standards are insufficiently harmonized with national laws and regulations, resulting in a regulatory gap. This disconnect is often exploited by contractors to obscure negligence, errors, or inadequate expertise, exacerbating the challenges in ensuring safe and reliable LV electrical installations.

Key Words: Electrical installations, connection, overhead network, cable network, grounding, residual current protective device.

1. INTRODUCTION

Low Voltage (LV) Power Supply Systems can be: TN, TT, and IT, as explained in the literature [1] - [15]. The most commonly used systems in LV networks are TN and TT, while IT systems are utilized for special purposes in areas where uninterrupted power supply is critical (e.g., mines, hospitals, chemical industries, etc.). The letters used in these systems have the following meanings:

- First letter – indicates the relationship of the power system to the earth:
  - T: Direct connection of one point to the earth.
  - I: All live parts are isolated from the earth, or one point is connected to the earth through an impedance with high resistance.
- Second letter – indicates the relationship of exposed conductive parts of the installation to the earth:
  - T: Direct electrical connection of exposed conductive parts to the earth, independent of any grounding of the power system.
  - N: Direct electrical connection of exposed conductive parts to the grounded point of the power system (in AC systems, the grounded point is usually the neutral point, or if the neutral point is not available, one of the line conductors).
- Subsequent letter**(s)** (if present) – indicate the arrangement of neutral and protective conductors:
  - S: The protective function is provided by a conductor separate from the neutral conductor or from the grounded line conductor (or, in AC systems, the grounded phase conductor).
  - C: The neutral and protective functions are combined in a single conductor (PEN conductor).

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Figures 1, 2, 3, and 4 illustrate the grounding power supply systems that are most commonly used [14].

The **TN-C/S system** is the most commonly used system for overhead connections when dealing with a grounded (nullified) network, or the **TT system** for facilities with their own grounding.

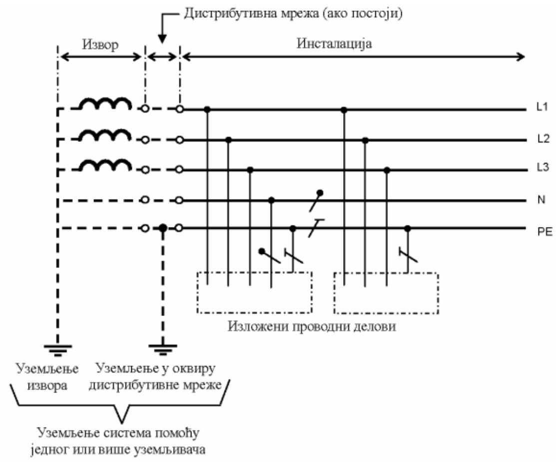

Figure 1 *- TN-S system with a separate neutral conductor and protective conductor throughout the entire system.*

Figure 2 - TN-C/S system where the PEN conductor is split into PE and N in one part of the installation.

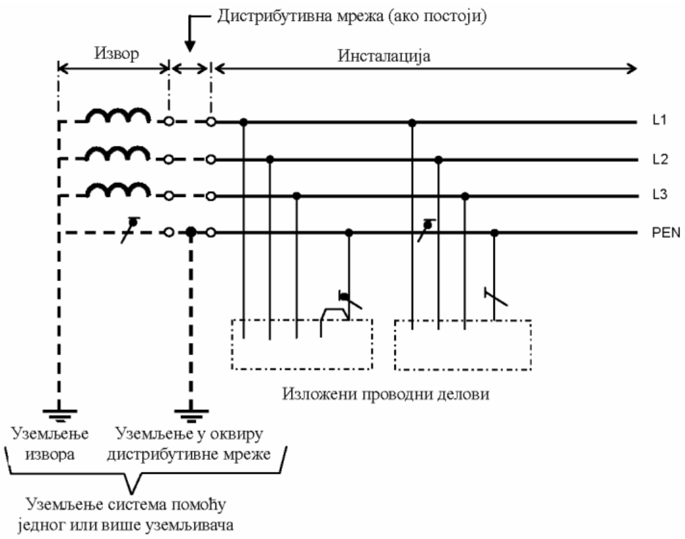

Figure 3 - TN-C system in which the functions of the neutral and protective conductor are combined into a single conductor throughout the entire system [14].

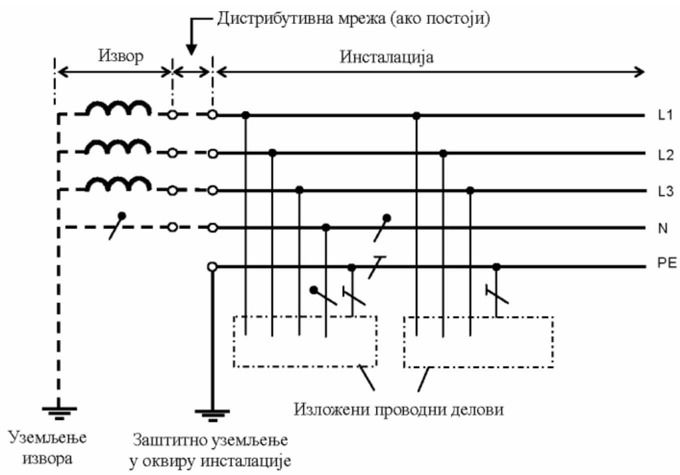

Figure 4 - TT system with separate neutral and protective conductors throughout the entire installation.

2. CONNECTION OF A BUILDING TO AN OVERHEAD LOW-VOLTAGE NETWORK

The overhead low-voltage (LV) network consists of four conductors (usually Al-Fe wires), three phase conductors, and a neutral conductor. These conductors are carried on poles using porcelain insulators. The connection to a building is established by installing a metal bracket with an appropriate clamp and insulators on the building, where the overhead line is terminated. From the bracket, the connection continues with copper (less commonly aluminum) conductors to the distribution cabinet or distribution board. The transition from aluminum to copper conductors is made using combined Al-Cu clamps.

The overhead line is not considered a fixed installation due to the possibility of interruptions or contact of the neutral conductor with phase conductors or the ground, as well as breaks in phase or neutral conductors caused by various mechanical stresses: trees falling on the lines, breakage due to accumulated snow and ice, overloading from strong winds, heavy loads from large numbers of birds perched on the lines, etc.

This brings us to the first issue with connections: since an overhead line is not a permanently fixed line, it is considered a temporary installation. Thus, the installation of a Residual Current Device (RCD), commonly known as an FID switch, is mandatory, regardless of whether the system is TN or TT. However, some electricity distributors believe this measure applies only to household installations, leading to discrepancies: in Vojvodina, the RCD is mandatory for overhead connections, while in other parts of Serbia, distributors consider it unnecessary.

Electricity distribution companies have their own rules and regulations for connections, but these regulations should be standardized at the national level. It is generally agreed that the standards and regulations adopted by the Republic of Serbia take precedence over the regional rules of individual electricity distributors.

The *"Regulations on Technical Standards for the Protection of Low-Voltage Networks and Associated Transformer Stations"* (*Official Gazette of the SFRY*, No. 13/78, and *Official Gazette of the FRY*, No. 37/9), Article 23, states:
"An overhead low-voltage network constructed with self-supporting cables must meet the same grounding requirements as underground cable networks." [5]

This means that an overhead low-voltage network constructed with self-supporting cables (SSC) can be considered equivalent to an underground cable network, i.e., a permanently fixed network. In such cases, an RCD is not required if the other grounding conditions for a TN network, prescribed in Articles 41 and 42 of this regulation, are met. These conditions are the responsibility of the electricity supplier.

3. CONNECTION OF A BUILDING TO AN OVERHEAD LOW-VOLTAGE TN SYSTEM

If a building connected to an overhead low-voltage network employs grounding, the following condition must be met. Standard SRPS HD 60364-5-54:2012, section 543.4.1, states:

"PEN, PEL, or PEM conductors may only be used in fixed electrical installations and, for mechanical reasons, must have a cross-sectional area of not less than 10 mm² for copper or 16 mm² for aluminum." [13]

However, very often, particularly for smaller buildings such as weekend houses, kiosks, and similar structures, contractors install supply cables with cross-sections as small as 4 x 6 mm² or even less. They then proceed to separate the PEN conductor into PE (protective earth) and N (neutral) conductors within the distribution cabinet, if present, or at the distribution board. This practice violates the aforementioned standard.

Contractors justify this by arguing that: these are small-load consumers, larger cross-sections are unnecessary and oversized, the specified cross-section is merely a recommendation from electricity distribution companies. Such practices raise the question: What is the purpose of standards? Standards are designed to ensure the safety and reliability of electrical installations. Ignoring these requirements compromises both mechanical durability and electrical safety, leading to potential risks. Figures 5, 6, and 7 provide examples of improper separation of the PEN conductor into PE and N conductors [13].

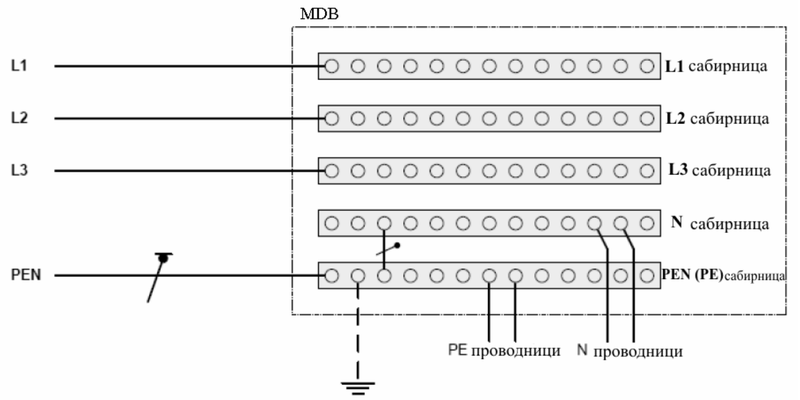

Figure 5 – Example 1

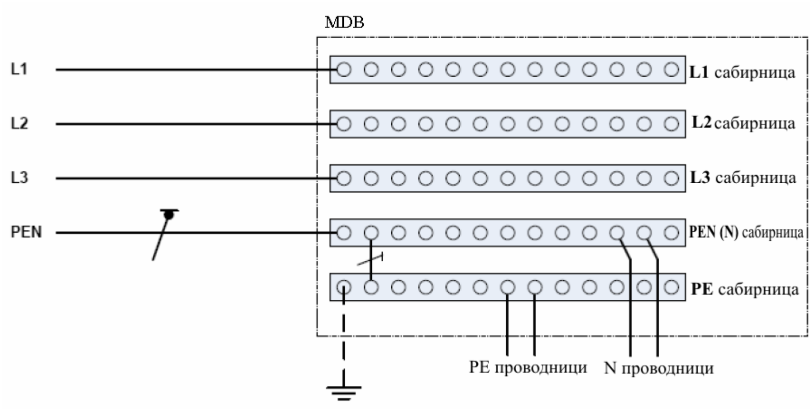

Figure 6 – Example 2

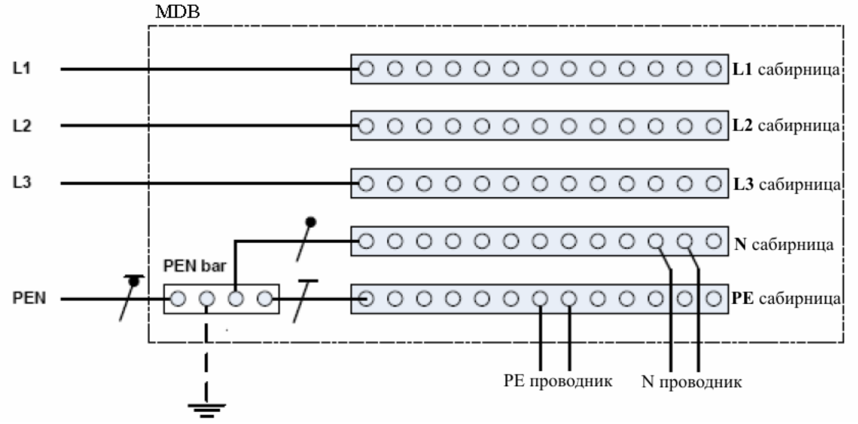

Figure 7 – Example 3

Section 543.4.3 of this standard states: "If, from any point in the installation, the functions of the neutral point/midpoint/line and the protective function are provided by protective conductors, it is not permitted to connect the neutral point/midpoint/line conductor to any other grounded part of the installation [13]. However, it is allowed to create multiple neutral point/midpoint/line conductors and multiple protective conductors from PEN, PEL, or PEM conductors, respectively." This means that once the PE (protective earth) and N(neutral) conductors are separated, they must not be reconnected, nor should the PE conductor be connected to other grounded parts of the installation. However, contractors often fail to comply with this requirement and frequently reconnect the PE (protective earth) and N (neutral) conductors in subsequent distribution cabinets or boards, where the cross-sections are smaller. When a break occurs in the neutral conductor, this leads to excessive overheating of the PE conductor, which can cause a fire, especially in older buildings with wooden distribution cabinets. An even more severe situation arises when PE and N conductors are reconnected directly at the outlet or on the appliance itself, such as a water heater, fan, or electric motor. This can have catastrophic consequences in terms of: Electrical safety, increasing the risk of electric shock, Fire protection, as improper grounding raises the likelihood of overheating and ignition. Such cases are also observed in newer buildings, even those constructed in high-end locations.

To save costs, smaller buildings are often constructed without a dedicated distribution cabinet, and the electricity meter is installed directly on the distribution board inside the building, which makes reading the meters more difficult. However, in recent times, there has been a shift towards placing electricity meters in external distribution cabinets located on poles or in dedicated enclosures outside the user's property. Larger buildings in the TN system, such as residential buildings, industrial facilities, schools, public institutions, etc., typically have a foundation grounding system that is, as a rule, connected to the PEN or PE conductor.

The foundation grounding lead, or the main grounding conductor, should be connected to the main grounding busbar at the point where the power supply enters the building. From there, it is further connected to the PEN or PE conductor. However, contractors often connect the foundation grounding to the nearest point of the PE conductor, regardless of its location relative to the main grounding busbar. This practice poses a significant safety issue for the building, particularly in terms of protection against electric shock. This problem is also present in TT protection systems, where proper grounding is equally critical for ensuring electrical safety.

4. CONNECTION OF A BUILDING TO AN OVERHEAD LOW-VOLTAGE NETWORK IN A TT SYSTEM

The connection of a building to an overhead low-voltage network is performed similarly to the TN system, using four conductors (three phase conductors and one neutral), as shown in Figure 4, which are then routed to the main distribution cabinet. All exposed conductive parts of the electrical installation must be connected via a protective conductor (PE) to the building's grounding system, which serves as the common grounding point for all these parts. The main distribution cabinet must include a main grounding busbar, where the grounding electrode is connected. From this busbar, the PE conductor is formed and distributed throughout the installation. Achieving low resistance with individual grounding electrodes is challenging, and the overhead network is not considered a fixed installation. According to Standard SRPS HD 60364-4-41:2017, section 411.5.2: In TT systems, RCDs (Residual Current Devices) must be used as a rule for fault protection (protection against indirect contact), Alternatively, overcurrent protection devices may be used for fault protection if a permanently and reliably low value of Zs (fault loop impedance) can be ensured. [16].

According to the Regulations on Technical Standards for Low-Voltage Electrical Installations (*Official Gazette of the SFRY*, Nos. 53/88, 54/88, and *Official Gazette of the FRY*, No. 28/95), an overhead network can be considered a permanently installed system on shorter sections if reliable mechanical safety is ensured, preventing conductor breaks, especially of the neutral conductor. When an RCD (Residual Current Device) is used for fault protection (protection against indirect contact), the circuit should also be protected by an overcurrent protection device, in accordance with Standard SRPS HD 60364-4-43:2012. In practice, it is frequently observed that fault protection in electrical installations is provided solely by an RCD. This is a significant error because, according to Standard SRPS HD 60364-4-41:2017, the RCD is considered supplementary protection, not primary protection. The primary protection for electrical installations must consist of overcurrent protection devices, such as: Fuses, Circuit breakers, Protective switches. These devices are essential for ensuring the safety and reliability of the installation, with the RCD serving as an additional layer of protection.

It is unfortunate that many contractors fail to distinguish between the principle of protection provided by an RCD (Residual Current Device**)** and the principle of protection provided by overcurrent protection devices. Figure 8 illustrates the principle of protection using an RCD (FID switch) and overcurrent protection devices (fuses). The RCD reacts to an imbalance of current in the conductors (protection against indirect contact) but does not respond to a short circuit between conductors. For short-circuit protection, fuses or circuit breakers are used. Figure 9 shows the actual appearance of an RCD (FID switch). According to Standard SRPS HD 60364-5-54:2012, for line conductor cross-sections of **S** $\leq$ 16 mm², the protective conductor must have the same cross-section as the line conductor [13]. In most cases within TT systems, contractors do not comply with this requirement and use significantly smaller cross-sections for protective conductors. They justify this by claiming: The protective conductor does not carry current, There is no need for such a large cross-section. This approach is incorrect and compromises safety, as the protective conductor must be adequately sized to ensure reliable fault protection and mechanical durability, as specified in the standard. Contractors frequently perform grounding (neutralization) in TT systems on their own, without the approval of the electricity distribution company. This practice causes significant problems for the distribution company, particularly with the adjustment of protection systems, which are increasingly electronic and highly sensitive. Moreover, this unauthorized grounding poses risks to the supplied building, including: Fire hazards, Touch voltage risks in the event of a fault. Proper coordination and compliance with distribution company regulations and standards are essential to ensure both system reliability and safety for the connected building.

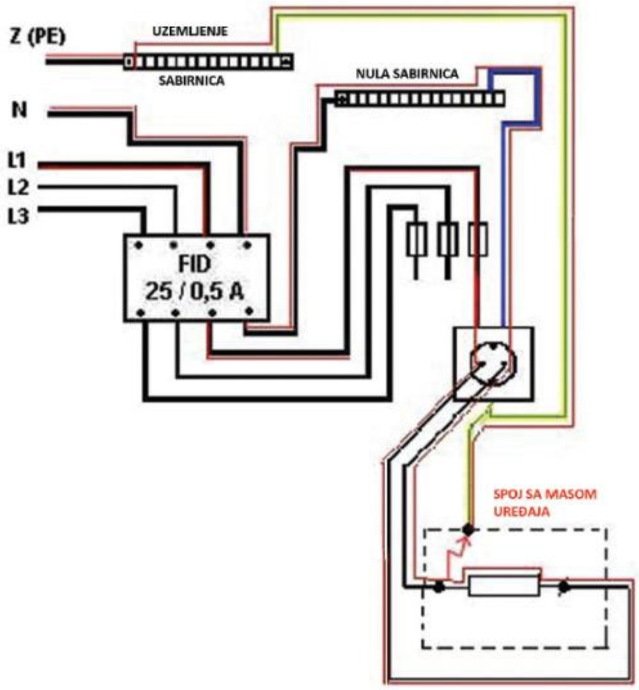

Figure 8 - Protection of Electrical Installations

Figure 9 – Actual Appearance of an RCD (FID Switch)

Electric distribution TT networks are primarily implemented in rural areas due to the scattered nature of buildings. Similar to overhead TN systems, the use of RCDs (Residual Current Devices) is mandatory in some regions, such as Vojvodina. However, most electricity distribution companies in Serbia allow connections without an RCD. Additionally, institutions responsible for inspecting and testing electrical installations have divergent views on this issue, leading to inconsistent practices and varying levels of protection in TT networks.

5. CONNECTION OF A BUILDING TO A CABLE LOW-VOLTAGE NETWORK

In recent times, buildings are predominantly connected to low-voltage networks using underground cables or overhead SKS cables (self-supporting insulated cables), which are also treated as cable networks. For these connections, the use of an RCD (FID switch) is not mandatory, as these are fixed installations. However, conditions for low fault loop impedance (Zs) must be met to ensure that overcurrent protection devices (such as fuses, circuit breakers, protective switches, etc.) operate within the specified time limits and disconnect the circuit in the event of overcurrent caused by a fault. The disconnection times are provided in Table 1, according to Standard SRPS HD 60364-4-41:2017, sections 411.3.2.2, 411.3.2.3, and 411.3.2.4.

Table 1 - Maximum Disconnection Times

System	50 V< U_0 ≤ 120 V [s]		120 V< U_0 ≤ 230 V [s]		230 V< U_0 ≤ 400 V [s]		U_0 > 400 V [s]	
	Alternating Current (AC)	Direct Current (DC)	Alternating Current (AC)	Direct Current (DC)	Alternating Current (AC)	Direct Current (DC)	Alternating Current (AC)	Direct Current (DC)
N	0,8	note	0,4	1	0,2	0,4	0,1	0,1
T	0,3	note	0,2	0,4	0,07	0,2	0,04	0,1

TN System**:** Exposed conductive parts are connected to the earth along with the grounded point of the power supply system.

TT System**:** Exposed conductive parts are connected to the earth independently of the power supply system. [16]

When, in a TT system, disconnection is achieved using an overcurrent protection device, and the protective equipotential bonding is connected to all extraneous conductive parts in the installation, the maximum disconnection times applicable to TN systems may be used.

U_0 - is the nominal AC or DC voltage of the phase relative to earth.

Disconnection times must comply with Table 1. For distribution circuits, distribution cabinets, end consumers, and certain other special cases: In TN systems, disconnection times must not exceed 5 seconds, In TT system, disconnection times must not exceed 1 second.

In TN and TT systems, the characteristics of protective devices and the fault loop impedance (Zs) must satisfy the following condition:

$$Zs \times Ia \leq U0$$

Where: Zs - impedance, in ohms (Ω), of the fault loop, consisting of:

For TN systems: the source, the line conductor to the fault point, and the protective conductor between the fault point and the source.

For TT systems: the source, the line conductor to the fault point, the protective conductor of exposed conductive parts, the grounding conductor, the installation grounding electrode, and the source grounding electrode.

- Ia - current, in amperes (A), that ensures automatic operation of the circuit-breaking device within the disconnection times specified in Table 1.

- U_0 - nominal voltage of the line conductor relative to earth, in volts (V).

If this condition cannot be met, an RCD (Residual Current Device) must be used for fault protection (protection against indirect contact voltage), except in TN-C systems, where the protective and neutral conductors are combined.

In TT systems, the following condition must also be met:

$$Ra \times \Delta In \leq 50\ V$$

Where:

- R_a - sum of the resistance of the grounding electrode (in Ω) and the protective conductor of the exposed conductive parts.

- ΔI_n - rated residual operating current of the RCD device, in amperes (A). [16]

6. CONCLUSION

The connection of a building to a low-voltage network may seem very simple at first glance, but a deeper analysis of the issue reveals numerous uncertainties that need to be resolved, making it a complex problem. A significant challenge lies in the **legal framework**, which has not clearly defined this process, requiring conclusions to be drawn through the use and analysis of multiple regulations and standards in this field. Additionally, a major issue is posed by the **internal recommendations** of electricity distribution companies and other legal entities involved in connecting buildings to low-voltage networks.

Almost every electricity distribution company has its own internal recommendations, which are not aligned with the legal framework for this field at the national level in Serbia. Contractors look for ways to cut costs on materials and labor, without paying attention to the quality of the work performed or the safety of the personnel who will use these installations later. Ultimately, all of this happens in plain view of: the Designer, the Revision Authority, the Supervisory Authority, the Personnel Responsible for work inspections at the contractor, the Personnel Conducting Electrical Installation Inspections, the Technical Review Commission, and the Electricity Distribution Company, which accepts and approves these installations.

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