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Software de fácil manejo para el cálculo y la selección de conductores eléctricos conforme a la normativa sobre instalaciones de edificios

User-friendly software for electrical conductor calculations and selection in compliance with rebt regulations for building installations

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Resumen-- **La generación de electricidad va seguida de su transmisión a través de líneas eléctricas de alta tensión, hasta llegar a las instalaciones receptoras y edificios designados para su consumo. Tal y como se especifica en el Reglamento Electrotécnico de Baja Tensión (REBT), las instalaciones eléctricas de baja tensión (<1000V AC) en España deben cumplir unos estrictos criterios de diseño, que abarcan los métodos de instalación de los conductores, el espaciado, el tipo, etcétera. El programa desarrollado en este trabajo simplifica el cálculo de las secciones de los conductores de fase y, en su caso, neutro, garantizando el cumplimiento de las directrices específicas del REBT. La aplicación ofrece resultados en cuestión de segundos, liberando a los usuarios de cálculos manuales y búsquedas reglamentarias. Se aplican los principales métodos en instalaciones de baja tensión para la determinación del área de la sección transversal: cálculos basados en criterios de calentamiento térmico y evaluaciones de caída de tensión. La aplicación está disponible en https://www.uhu.es/dietdp/espacios_p3.php?login=1**

Palabras clave— Herramienta de diseño de instalaciones eléctricas; Aplicación de fácil manejo; Reglamento Electrotécnico de Baja Tensión (REBT).

Abstract— **The generation of electricity is followed by its transmission through high-voltage power lines, reaching designated receiving facilities and buildings for consumption. As specified in the Low Voltage Electrotechnical Regulations (REBT from the Spanish "Reglamento Electrotécnico de Baja Tensión"), low-voltage electrical installations (<1000V AC) in Spain must adhere to strict design criteria, encompassing conductor installation methods, spacing, type, and so forth. The developed program disclosed in this paper simplifies the calculation of phase and, if applicable, neutral conductor cross-sectional areas, ensuring compliance with REBT specific guidelines. The application delivers results within seconds, liberating users from manual calculations and regulatory searches. The main methods in low-voltage installations for cross-sectional area determination are applied: thermal heating criterion-based calculations and voltage drop assessments. The app is available in https://www.uhu.es/dietdp/espacios_p3.php?login=1**

Index Terms— Electrical installation designing tool; User-friendly application; Low Voltage Electrotechnical Regulations (REBT).

I. INTRODUCTION

A safe and efficient electrical installation is an essential component of any building, from private residences to industrial complexes and commercial spaces. Ensuring compliance with regulations and optimizing energy performance during the design of the electrical installation can be a tedious and error-prone process.

This paper presents an innovative tool designed to simplify and expedite the design process of low-voltage electrical installations. This user-friendly tool enables professionals and installers to quickly calculate the cross-sectional areas of phase

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and neutral conductors, while simultaneously ensuring compliance with current regulations (*BOE-A-2002-18099 Real Decreto 842/2002, de 2 de Agosto, Por El Que Se Aprueba El Reglamento Electrotécnico Para Baja Tensión.*, n.d.).

Instead of relying on manual calculations and cumbersome searches through regulations, this application provides results in a matter of seconds, freeing users from tedious tasks and allowing them to focus on more strategic aspects of the project.

The design of low-voltage electrical installations is a widely studied field with numerous tools and methodologies available. However, many of these solutions are complex and require specialized knowledge, making them inaccessible to a broad spectrum of users. Furthermore, traditional methods for calculating conductor cross-sectional areas are often laborious and error-prone, as they involve manual calculations and searches through regulations. In response to these limitations, various software tools have been developed to automate the process of electrical installation design. These tools vary in complexity and functionality, but all share the goal of simplifying and expediting the design process. For example, ELEC CALC by tracesoftware ('elec calc$^{\text{TM}}$ software de cálculo multi-estándar', n.d.) is proprietary software solutions designed for electrical installations design and calculation. This program, like any other engineering software, requires a certain level of technical expertise as it offers a wide range of solutions. In contrast, there are free applications provided by commercial companies that offer commercial cable cross-sections and suggest it from the same company that provides the tool, such as Nexans EASYCALC (*Nexans EASYCALC^{TM}*, n.d.), TOPMATIC (*TopMatic*, n.d.), Prysmian Group (*Cálculo de Sección de Cable | Cable App General Cable | Prysmian Group*, n.d.) and many more.

While these tools offer a variety of benefits, some of them may be costly, require specialized technical knowledge, or have a steep learning curve. The existing commercial applications are limited to providing commercial sections, especially those provided by the manufacturers. There is a clear need for a low-voltage electrical installation design tool that is accessible, user-friendly, and meets the needs of a wide range of users, offering the following characteristics:

- Ease of use: The tool must have an intuitive and user-friendly interface that does not require specialized technical knowledge.
- Accessibility: The tool should be affordable for individual users, small businesses, and independent professionals.
- Regulatory compliance: The tool must ensure compliance with current regulations for low-voltage electrical installations.
- Accuracy: The tool should provide accurate and reliable results.
- Efficiency: The tool should enable users to complete the design process quickly and efficiently.

The proposed application here provides the exact technical sections, informs the commercial one and indicates the criteria that prevails for the selection. It computes isolated lines within electrical installations, distinct from the integrated diagram, while allowing users to specify the starting point within the diagram as part of the input data. Furthermore, the program provides the following features: a user manual, complementary technical instructions (ITCs) for different installations, and the option to export results in different formats.

II. MATERIALS AND METHODS

This section provides an overview of the materials and methods utilized in the investigation. The software tools employed are detailed, and the methodology used to analyse and determine the cross-sectional areas of conductors is outlined.

A. MATERIALS

The development of the tool for calculating cross-sectional areas of conductors in low-voltage electrical installations has been carried out using MATLAB software (*MATLAB - El lenguaje del cálculo técnico*, n.d.) and its application creation environment, App Designer. MATLAB is a programming language and numerical computing environment developed by MathWorks. It is widely used in various fields, including engineering, science, finance, and software development (Naim et al., 2017) (Kim et al., 2003). MATLAB offers a wide range of tools for data analysis, visualization, and algorithm development.

App Designer is a graphical application creation environment included in MATLAB (*MATLAB App Designer - MATLAB & Simulink*, n.d.). It allows users to create applications with intuitive user interfaces without requiring deep programming knowledge. App Designer uses the MATLAB programming language for application logic and integrates with other MATLAB tools for data analysis and visualization.

B. METHODS

To calculate the conductor section of an electrical line in an installation, it is necessary to apply a series of criteria regulated by the REBT. These criteria are:

- Thermal criterion for long term: heating. The intensity is limited at which the current begins to deteriorate the insulating material of the conductor due to Joule heating.
- Voltage drop criterion: A maximum voltage drop is defined, which cannot be exceeded by the conductors. This criterion aims to establish a maximum allowable voltage drop.
- Thermal criterion for short term: short circuit. Establishing a short-circuit time during which the material should not suffer any damage if the mentioned phenomenon occurs.

Only the first two criteria will be developed since they have been used in the program; the thermal criterion for short circuit does not prevail in this type of installations and is left for implementation in future versions. Before the calculation, it will be necessary to have a clear understanding of a series of basic data in all types of installations, such as how and where it will be installed: underground, overhead, or indoor.

The REBT is a document that contains all the instructions to ensure safety for both material goods and individuals, as well as to ensure electrical continuity and efficiency in the installation. It is published in the Official State Gazette (BOE as acronym in Spanish) and is mandatory.

The REBT is divided into Complementary Technical Instructions (ITC), classified according to the topic to be addressed. For this work, only those related to overhead, underground, and indoor installations were needed; ITC-BT-06, ITC-BT-07, and ITC-BT-19 respectively.

1) Thermal criterion for long term: heating

The thermal model of the cable for determining the maximum current criteria involves understanding how heat is generated and dissipated within the cable when current flows through it (Roger Folch et al., 2021). This model aims to ensure that the temperature of the cable remains within safe limits, preventing overheating and potential damage to the insulation material.

Generated heat ($\boldsymbol{Q_g}$): When current flows through the conductor, heat is generated due to the resistance of the material (Joule effect). This heat generation is proportional to the square of the current flowing through the conductor, the length of the conductor, and inversely proportional to the cross-sectional area of the conductor. The formula for generated heat is expressed as:

$$\frac{dQ_g}{dt} = P_R = R \cdot I^2 = \frac{\rho \cdot L \cdot I^2}{S} \qquad (1)$$

Where $\frac{dQ_g}{dt}$ is the rate of heat generation, P_R is the power dissipated as heat, R is the resistance of the conductor, I is the current flowing through the conductor, ρ is the resistivity of the conductor material, L is the length of the conductor and S is the cross-sectional area of the conductor.

Emitted or Dissipated Heat ($\boldsymbol{Q_e}$): Heat is emitted or dissipated from the conductor to the surroundings, primarily through the insulation material surrounding the conductor. The rate of heat dissipation depends on factors such as the thermal conductivity of the insulation material, the surface area of contact, and the temperature difference between the conductor and the surroundings. The formula for emitted heat is expressed as:

$$\frac{dQ_e}{dt} = k_T \cdot S_c \cdot (T_i - T_e) = k_T \cdot L \cdot p(T_i - T_e) \qquad (2)$$

k_T is the thermal conductivity of the insulation material, S_c is the contact surface area, T_i is the temperature of the conductor, T_e is the ambient or external temperature and p is the perimeter of the conductor.

Internal Heat ($\boldsymbol{Q_i}$): The internal heat is the difference between the heat generated and the heat emitted. It represents the net heat accumulation within the conductor. The formula for internal heat is expressed as:

$$Q_i = Q_g - Q_e \quad \rightarrow \quad \frac{dQ_i}{dt} = C_e \cdot V_{ol} \cdot \frac{dT_i}{dt} = C_e \cdot L \cdot S \cdot \frac{dT_i}{dt} \qquad (3)$$

Conservation of Energy: By equating the rates of heat generation and dissipation, we ensure that the conductor reaches a steady-state temperature without excessive heating or cooling. This leads to the conservation of energy principle, expressed as:

$$C_e \cdot S^2 \cdot \frac{dT_i}{dt} = \rho \cdot I^2 - k_T \cdot p \cdot S \cdot (T_i - T_e) \qquad (4)$$

The objective of this criterion is to ensure that the temperature of the conductor in steady state never exceeds the maximum temperature, as represented. Steady state refers to the time during which the conductor will carry the nominal design current.

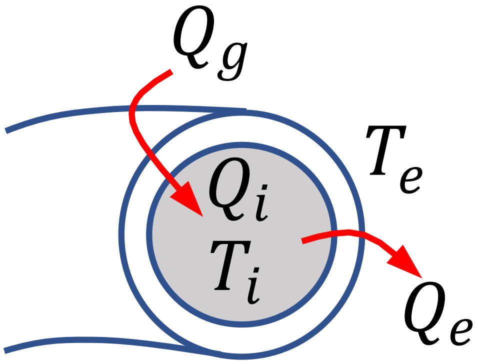


Fig. 1. Cable thermal model

It is possible to arrive at an expression by knowing that in steady state, the heat generated will always be equal to the heat dissipated, with the internal heat remaining constant. If a maximum temperature $T_{i\,max}$ at which the insulation begins to deteriorate is assumed, the maximum permissible current I using the following expression can be calculated:

$$I = \sqrt{\frac{k_T \cdot p \cdot S}{\rho_{max}} (T_{i_{max}} - T_e)} \qquad (5)$$

This expression allows for the calculation of maximum currents for different insulating materials while also considering the resistivity of both copper and aluminium conductor materials. By considering these factors, engineers can ensure that the electrical system operates within safe temperature limits, preventing insulation damage and ensuring system reliability.

2) Voltage drop criterion

To size conductors based on voltage drop, the aim is to limit the voltage loss across the conductors. The goal is to avoid excessive voltage drop from the beginning to the end of the electrical installation. An equivalent circuit of the electrical installation is used (Colmenar Santo & Hernández Martín, 2012), see figure 2, comprising a voltage source V_1 at the input, voltage drop in the line V_R and V_L, and the voltage at the load V_2. By applying Kirchhoff's second law, the voltage drops across the line ΔV_{Line} is defined as the difference between the input and output voltages:

$$\Delta V_{Line} = V_1 - V_2 \qquad (6)$$

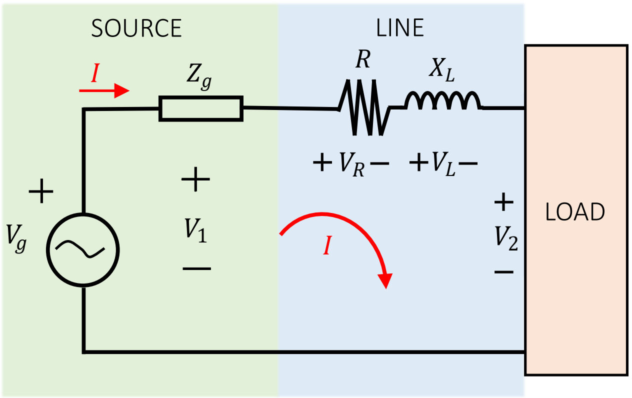


Fig. 2. Equivalent circuit of electrical installations

After analysing the circuit considering the resistive and inductive components and making simplifications based on the resulting phasor diagram, the following expression is achieved:

$$\Delta V_L = V_1 - V_2 = RI\cos\varphi + X_L I\sin\varphi \tag{7}$$

Considering that the installations can be single-phase or three phases, it is imperative to add a new constant:

$$\Delta V_L = k_f RI\cos\varphi + k_f X_L I\sin\varphi \tag{8}$$

Where k_f can be 2 (single phase line) or $\sqrt{3}$ (three-phase line), R is the line resistance that is:

$$R = \frac{\rho \cdot L}{S} \tag{9}$$

Finally, the relationship between voltage drops and conductor size S, is stablished as:

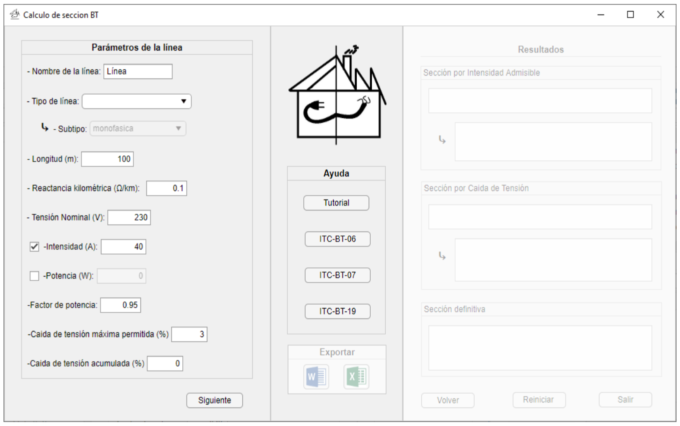
$$\Delta V_L = k_f \cdot \frac{\rho \cdot L}{S} \cdot I \cdot \cos\varphi + k_f \cdot X_k \cdot L \cdot I \cdot \sin\varphi \tag{10}$$

III. RESULTS

After explaining the theoretical basis on which the Low Voltage Section Calculation program is based, we proceed to dissect the created interface and the actual operation of the application.

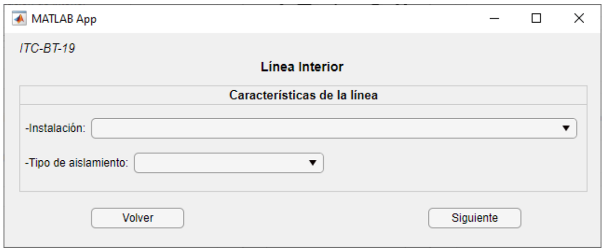
A. App interface

When initiating the program, the main window, as shown in Figure 3, is displayed. This window is divided into three panels. In the right panel, parameters for the line calculation are inputted. In the centre panel, there are help buttons providing a manual of the application and access to various Technical Complementary Instructions (ITC), along with buttons enabled for exporting results. Finally, in the left panel, the calculated results from the various methods previously discussed are displayed.

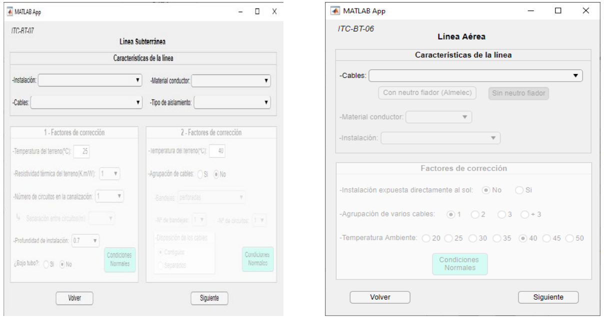


Parámetros de la línea
- Nombre de la línea: Línea
- Tipo de línea:
↳ - Subtipo: monofasica
- Longitud (m): 100
- Reactancia kilométrica (Ω/km): 0.1
- Tensión Nominal (V): 230
☑ -Intensidad (A): 40
☐ -Potencia (W): 0
-Factor de potencia: 0.95
-Caida de tensión máxima permitida (%) 3
-Caida de tensión acumulada (%) 0

Fig. 3. Program main interface: line parameters



a) *Indoor*



Temperatura del terreno(°C): 25
Resistividad térmica del terreno(K.m/W): 1
Número de circuitos en la canalización: 1
Profundidad de instalación: 0.7
¿Bajo tubo?: ○ Si ● No
Temperatura del terreno(°C): 40
Agrupación de cables: ○ Si ● No
Bandejas: perforadas
Nº de bandejas: 1
Nº de circuitos: 1
Disposición de los cables: ● Contiguos ○ Separados

-Instalación expuesta directamente al sol: ● No ○ Si
-Agrupación de varios cables: ● 1 ○ 2 ○ 3 ○ + 3
-Temperatura Ambiente: ○ 20 ○ 25 ○ 30 ○ 35 ● 40 ○ 45 ○ 50

b) *Underground* ***c)*** *Overhead*

Fig. 4. Applets window to characterize the line for a) Indoor b) Underground c) Overhead

The operation cascades, meaning, first, the left and center panels are enabled, parameters are inputted, and the 'Next' button is pressed. Subsequently, depending on the type of line, windows shown in Figure 4 will open a) Indoor, b) underground, and c) overhead.

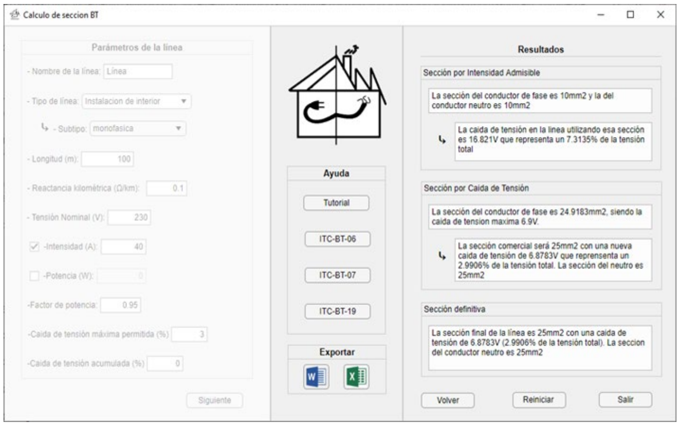
Once the user inputs the characteristics of the line in this new window, such as the installation mode, type of insulation, or conductor material, the user can proceed by pressing the 'Next' button. Finally, the user arrives at the window where the results are displayed, divided according to the method used to calculate the cable section.

As shown in Figure 5, the option to export the results is already available in the central panel, both in ".txt" and ".xls" formats.

Once reaching the end of the application, three options are available at the bottom: Go back, Restart, and Exit

3.2. Use case: underground

It would be possible to present all three types of installations,



- Nombre de la línea: Línea
- Tipo de línea: Instalacion de interior
↳ - Subtipo: monofasica
- Longitud (m): 100
- Reactancia kilométrica (Ω/km): 0.1
- Tensión Nominal (V): 230
☑ -Intensidad (A): 40
☐ -Potencia (W): 0
-Factor de potencia: 0.95
-Caida de tensión máxima permitida (%) 3
-Caida de tensión acumulada (%) 0

Sección por Intensidad Admisible

La sección del conductor de fase es 10mm2 y la del conductor neutro es 10mm2

↳ La caida de tensión en la linea utilizando esa sección es 16.821V que representa un 7.3135% de la tensión total

Sección por Caida de Tensión

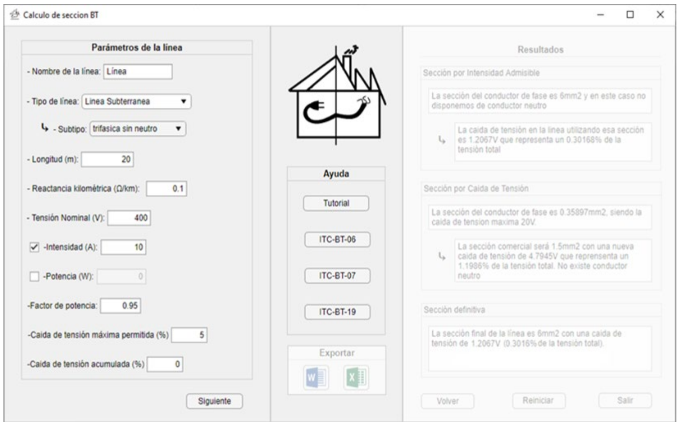
La sección del conductor de fase es 24.9183mm2, siendo la caida de tension maxima 6.9V.

↳ La sección comercial será 25mm2 con una nueva caida de tensión de 6.8783V que reprensenta un 2.9906% de la tensión total. La sección del neutro es 25mm2

Sección definitiva

La sección final de la línea es 25mm2 con una caida de tensión de 6.8783V (2.9906% de la tensión total). La seccion del conductor neutro es 25mm2

Fig. 5. Program main interface: results.



- Nombre de la línea: Línea
- Tipo de línea: Linea Subterranea
↳ - Subtipo: trifasica sin neutro
- Longitud (m): 20
- Reactancia kilométrica (Ω/km): 0.1
- Tensión Nominal (V): 400
☑ -Intensidad (A): 10
☐ -Potencia (W): 0
-Factor de potencia: 0.95
-Caida de tensión máxima permitida (%) 5
-Caida de tensión acumulada (%) 0

Sección por Intensidad Admisible

La sección del conductor de fase es 6mm2 y en este caso no disponemos de conductor neutro

↳ La caida de tensión en la linea utilizando esa sección es 1.2067V que representa un 0.30168% de la tensión total

Sección por Caida de Tensión

La sección del conductor de fase es 0.35897mm2, siendo la caida de tension maxima 20V.

↳ La sección comercial será 1.5mm2 con una nueva caida de tensión de 4.7945V que reprensenta un 1.1986% de la tensión total. No existe conductor neutro

Sección definitiva

La sección final de la línea es 6mm2 con una caida de tensión de 1.2067V (0.3016% de la tensión total).

Fig. 6. Underground case. Program main interface: line parameters.

but detailing one case is sufficient to illustrate the program. The case to present is an underground installation, using a three-phase line without neutral at 400V, with a line current of 10 A (power factor = 0.95), and a maximum voltage drop of 5% over 20 meters of conductor. Therefore, ITC-BT-07 will be used.

The line will be underground, with copper single-core conductors insulated with XLPE (Cross-Linked Polyethylene) under normal conditions.

As observed in Figure 8 according to the criterion of permissible current intensity, a conductor of 6mm² section is required. However, for voltage drop considerations, a 1.5mm² conductor is necessary.

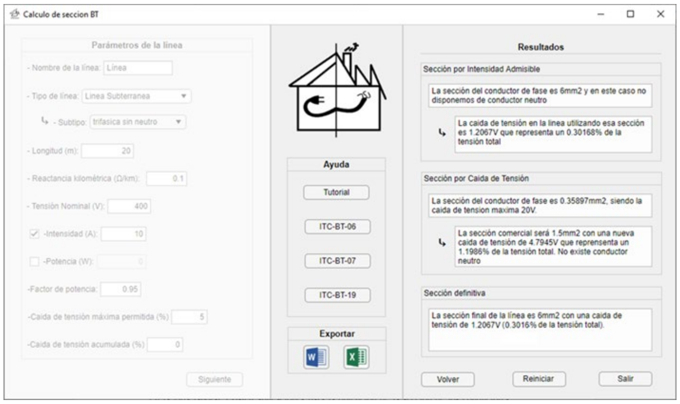
Therefore, in the final cross-section, it is obtained:

"The final section of the line is 6mm² with a voltage drop of 1.2067 (0.3016% of the total voltage)."

IV. CONCLUSIONS

In conclusion, the development of a user-friendly and efficient tool for calculating cross-sectional areas of conductors in low-voltage electrical installations represents a significant advancement in the field of electrical engineering. By automating the process and providing instantaneous results, the application simplifies the design process and ensures compliance with current regulations outlined in the Low Voltage Electrotechnical Regulations (REBT).

The utilization of MATLAB and its App Designer environment has facilitated the creation of an intuitive interface that does not require specialized technical knowledge to operate. This accessibility makes the tool suitable for a wide range of users, including individual professionals, small businesses, and independent contractors.



- Nombre de la línea: Línea
- Tipo de línea: Linea Subterranea
↳ - Subtipo: trifasica sin neutro
- Longitud (m): 20
- Reactancia kilométrica (Ω/km): 0.1
- Tensión Nominal (V): 400
☑ -Intensidad (A): 10
☐ -Potencia (W): 0
-Factor de potencia: 0.95
-Caida de tensión máxima permitida (%) 5
-Caida de tensión acumulada (%) 0

Sección por Intensidad Admisible

La sección del conductor de fase es 6mm2 y en este caso no disponemos de conductor neutro

↳ La caida de tensión en la linea utilizando esa sección es 1.2067V que representa un 0.30168% de la tensión total

Sección por Caida de Tensión

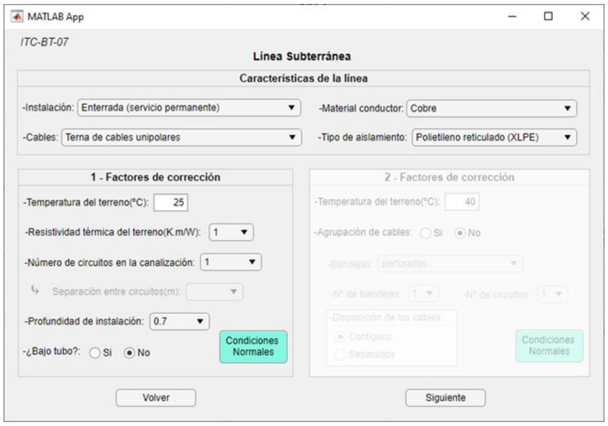
La sección del conductor de fase es 0.35897mm2, siendo la caida de tension maxima 20V.

↳ La sección comercial será 1.5mm2 con una nueva caida de tensión de 4.7945V que reprensenta un 1.1986% de la tensión total. No existe conductor neutro

Sección definitiva

La sección final de la línea es 6mm2 con una caida de tensión de 1.2067V (0.3016% de la tensión total).

Fig. 8. Underground case. Program main interface: results.



-Instalación: Enterrada (servicio permanente)
-Material conductor: Cobre
-Cables: Terna de cables unipolares
-Tipo de aislamiento: Polietileno reticulado (XLPE)

-Temperatura del terreno(°C): 25
-Resistividad térmica del terreno(K.m/W): 1
-Número de circuitos en la canalización: 1
↳ Separación entre circuitos(m):
-Profundidad de instalación: 0.7
-¿Bajo tubo?: ○ Si ● No

-Temperatura del terreno(°C): 40
-Agrupación de cables: ○ Si ● No
-Bandejas: perforadas
-Nº de bandejas: 1
-Nº de circuitos: 1
-Disposición de los cables:
● Contiguos
○ Separados

Fig. 7. Underground case. Applet window.

By focusing on the thermal criterion for heating and the voltage drop criterion, the application addresses key considerations in the design of electrical installations while leaving room for future improvements, particularly in addressing the thermal criterion for short circuits.

Overall, the proposed tool offers ease of use, affordability, regulatory compliance, accuracy, and efficiency, fulfilling the essential requirements for an effective electrical installation design solution. By providing technical sections, informing about commercial options, and indicating the prevailing criteria for selection, the application empowers users to make informed decisions and streamline the design process.Finally, taking advantage of the fact that the curves of February 3 exhibit a remarkable uniformity, Fig. 15, a simple regression analysis was carried out to obtain analytical equations that relate the illuminance, inside each model, with the time on a sunny day. Second-degree polynomial equations were obtained with coefficients of determination close to unity ($R^2 \approx 0.98$), indicating an excellent correspondence between the observed data and the predicted values.

TABLE I
RESULTS FOR UNDERGROUND USE CASE

Line name	**Line**	
Line type	Underground line	
Number of conductors	3 Phase	
Length	20	m
Line reactance	0.1	Ω/km
Nominal voltagel	400	V
Current	10	A
Power factor	0.95	
Maximum permissible voltage drops	3	%
Accumulated voltage drops	0	%
Phase section CT	6	mm^2
Actual permissible current	72	A
Correction factors Used	1 1 1 1 1 1	
Cross-section neutral CT	0	mm^2
Phase cross-section ΔV	1.5	mm^2
Neutral cross-section ΔV	0	mm^2
Final cross-section	3 x 6 Cu	
Conductor material	Copper	
Insulation	Cross-linked polyethylene (XLPE)	
Assigned Voltage	0,6/1	kV

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