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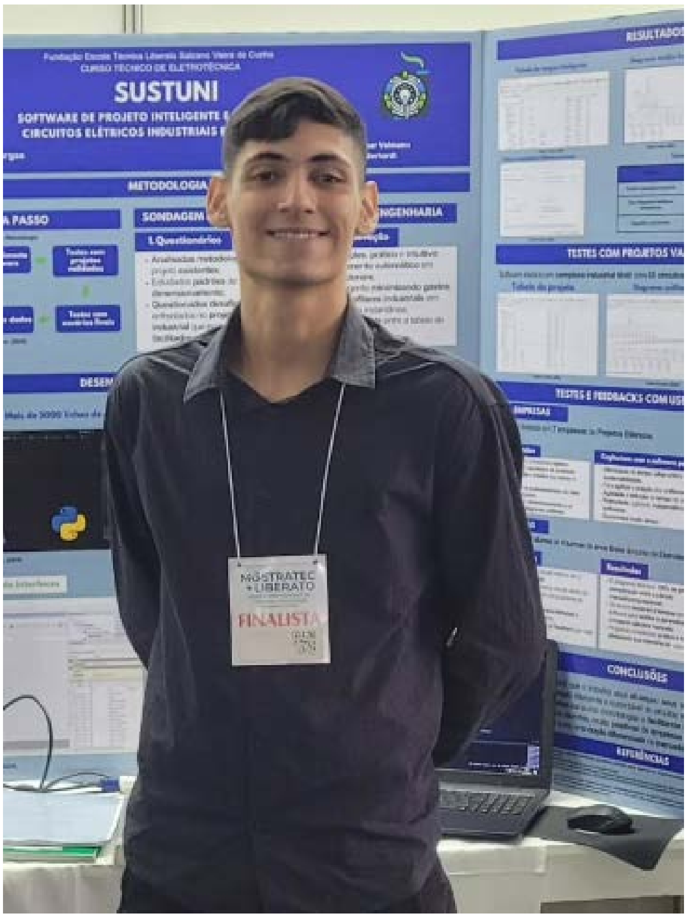

CURSO TÉCNICO DE ELETROTÉCNICA
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1. Questionários
RESULTADOS
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SUSTUNI

SOFTWARE FOR SMART AND SUSTAINABLE DESIGN OF INDUSTRIAL ELECTRICAL CIRCUITS

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ABSTRACT

The theme of this project is to develop software to facilitate and innovate the design of low-voltage industrial electrical circuits. The goal is to develop a program that makes projects more efficient in terms of time, accuracy, and sustainability, automating dimensions such as calculating conductor cross-sections, protections, single-line diagrams, and analyzing with AI at which points industrial electrical circuits can be more sustainable. The 2023 Electric Energy Yearbook of the Energy Research Company describes that electricity consumption increases 2% per year in Brazil, and industrial installations represent the largest part of the national electrical sector (36.2%). As stated in standard NBR 5410/2004, when developing an installation project, an electrical professional works with several processes, depending on several criteria and calculations to present a reliable electrical installation. Minimal errors in calculations can cause damage to equipment, conductors, and individuals present in the installation. Using software to model these circuits optimizes time and brings more confidence to the project. This work aims to differentiate itself in this field by filling in the gaps in existing solutions for the industry, providing support for Brazilian standards, automatically generating single-line diagrams and presenting suggestions for sustainability in the circuits. The program is developed in Python, based on NBR 5410/2004 and engineering works. The software developed allows the user to size different distribution boards, motors and circuits, calculating the cross-section of the conductors/electrical protections, a particular transformer, and generating a single-line diagram in CAD. The program also presents suggestions aimed at sustainability to reduce material/energy costs. Tests were carried out with electrical engineering companies and students in the technical area, where the software presented high precision and very positive feedback from the interviewees, and it can be said that the work achieved its objectives.

Keywords: Industrial Electrical Projects, electrical project software, sustainable industry.

1. INTRODUCTION

The demand for electricity increases by approximately 2% per year in Brazil, and Industrial Electrical Installations represent more than 36% of the national demand (EPE, 2023). When developing a project for a Low Voltage Industrial electrical installation, an electrical professional works with several complex and time-consuming processes, dependent on numerous criteria and calculations based on current standards (NBR 5410/2004) so that he can present a reliable and safe installation for the installation's end consumers of electricity. Among the main steps in the dimensioning of industrial electrical circuits, dimensions such as the calculation of the conductor cross-section stand out, divided between 3 criteria, NBR 5410/2004, and another 2 criteria for conductor protection; the minimum documentation required by NBR 5410 for the approval of a low voltage installation is: The installation plan, calculation report, single-line diagrams, and others when necessary. Furthermore, in an industry, electrical design requires even more steps and care than other types of installation (MAMEDE, João, 2017), such as the sizing of high-power electric motors, different types of panels, often the need for a transformer and a private substation unit, capacitor bank, among other parts, and minimal errors in the design of the project can cause serious problems in the final installation. Considering this, it is plausible and even necessary today to use software on computers to assist in the efficiency and accuracy of these projects, optimizing time and minimizing errors (SILVA, Antônio Carlos Pereira, 2020).

In this context, when analyzing the methods currently used to size industrial electrical circuits (described in sections 3.2 and 2.2 of this paper), we found certain deficiencies in the existing tools, such as: if you want to size industrial circuits using a software tool in Brazil, you will only find foreign programs that do not meet Brazilian standards and norms, and many of these programs are expensive and/or serve to promote equipment from a specific brand. In addition, none of these software programs automatically generate industrial single-line diagrams, something that can save the designer a lot of time, and they also ignore the possibility of presenting suggestions to make the industrial electrical design more sustainable, consuming less and contributing to the environment in the industry. This work aims to differentiate itself in this field by providing support for Brazilian standards, generating single-line diagrams automatically and presenting suggestions for sustainability in the circuits. The points that the software aims to meet are: Calculation of the cross-section of conductors and dimensioning of overcurrent protections, dimensioning of a particular transformer based on the installation demand, generation of a single-line diagram automatically from the load table, calculation of the power of a capacitor bank for correction of the power factor when necessary to correct the power factor, and presentation of sustainable suggestions. This development is mainly done through Object-Oriented Programming in Python integrated with the PySide6 framework, and uses Brazilian standards such as NBR 5410/2004 and works such as “Instalações Elétricas Industriais” (MAMEDE, João, 2017) as bibliography.

1.1 OBJECTIVES

1.1.1 General objective

Develop a software that facilitates and innovates the dimensioning of industrial electrical circuits, making them more efficient in terms of time, precision and sustainability, providing support for Brazilian standards, automatically generating single-line diagrams and suggesting sustainable approaches.

1.1.2 Specific Objectives

- Develop software in the Python programming language;
- Develop an algorithm to size the cross-section and protection of conductors in an industrial electrical project in accordance with Brazilian standards;
- Generate a single-line diagram using the software in CAD formats automatically based on the loads entered for future modifications;
- Size up to 2 individual transformers for installation;
- Present sustainable approaches to the industrial plant designer through an Artificial Intelligence algorithm.

2. BIBLIOGRAPHICAL REVIEW

2.1 The sizing process

Low-voltage industrial electrical circuits in Brazil are currently regulated by ABNT NBR 5410/2004. The standard's sizing criteria for electrical conductors include calculations based on their minimum cross-section, current-carrying capacity, voltage drop, overload protection, and short-circuit protection. These methods will be better described in later topics. In the mandatory documentation of an electrical project, the standard requires, at a minimum, the presentation of a floor plan, single-line diagrams (and others when applicable), in addition to the descriptive report of the installation, component specifications, and project parameters (NBR 5410/2004, item 6.1.8.1, p. 87).

2.2 Existing methodologies and areas of innovation

There are some examples of software that aims to size low voltage electrical installations on the market. The main ones found in the area are described below.

2.2.1 Academic works in the area

An example of a program that proposed to facilitate electrical design would be the final paper “AUXILIARY SOFTWARE FOR SIZING LOW VOLTAGE ELECTRICAL INSTALLATIONS” (DOS ANJOS, Rafael 2021), which managed to correctly calculate a limited number of circuits, but is limited to calculating the cross-section of residential installations. Another interesting project found was the master's dissertation entitled “Software application for sizing low voltage electrical installations” (LIMA, Tiago, 2021) which also proposes to calculate the cross-section of conductors. The solution presented is good for residential installations. All the works found in the field had certain limitations, such as capacitor banks and focusing on industrial installations.

2.2.2 Commercial programs

Based on the student's research and interviews with some companies in the area currently used, it was possible to analyze the most common methodologies used in the dimensioning of an industrial electrical project. Although most of the companies interviewed do not use dedicated software for the dimensioning of electrical installations, trying to automate their processes with Excel and/or AutoCAD, some are used, and the main ones in the area are listed below. Programs such as “PRO-Elétrica” (MULTIPLUS, 2024) and “Revit-Elétrica” (AUTODESK, 2024) are capable of performing a concise dimensioning of low-voltage building electrical circuits within Brazilian standards, and are the most used from what can be analyzed. However, these software programs do not meet the dimensioning requirements for industrial electrical installations, and are not a parameter for comparison with the main focus of the current work. Therefore, the main programs on the market for dimensioning industrial electrical circuits are foreign; Examples of applications for the industry would be “Cable Sizing Software” (ETAP, 2024), “DOC” (ABB 2024), Simaris, (Siemens, 2024) and Power Design (Schneider, 2024). The main positive points of these software are: Easy to obtain the values of admissible current, short-circuit and voltage drop; Sizing of the protection devices and cables used, assembly; Coordination and verification of cables and protection devices; Single-line block diagram.

As for the shortcomings: Complex and unintuitive interface, simple sizing errors occur frequently; Lack of automatic industrial single-line diagrams, requiring each section to be drawn manually; Little freedom of selection for the user, sizing focused on promoting company equipment; Does not comply with Brazilian standards and norms; Does not analyze points for less spending and more sustainability.

2.3 Sizing of Industrial Electrical Circuits

Below, a bibliographic review is described on how a low voltage industrial electrical installation is dimensioned, describing the 5 conductor dimensioning criteria.

2.3.1 THE 5 SIZING CRITERIA

Following an appropriate sequence for sizing conductors, according to NBR 5410/2004, the first criterion would be to define the minimum cross-section of the circuit. In item 6.2.6.1.1 (pg. 121), the standard states that the cross-section of phase conductors in alternating current circuits and of live conductors in direct current circuits must not be less than the relevant value given in table 47 (NBR 5410, 2004, pg. 121). For power loads and sockets, the minimum cross-section is 2.5 mm², and for lighting, 1.5 mm². For the 2nd criterion, ampacity, a series of factors must be taken into account to perform the sizing (NBR 5410, 2004), according to the topics in the following script: A. Type of insulation, according to table 35 of NBR 5410 (thermoplastic materials, e.g. PVC, and thermosetting materials, e.g. XLPE, EPR); B. Method of Installation (Table 33 of NBR 5410, example B1, B2, etc.); C. Calculation of design current – IB; D. Number of Loaded Conductors (Table 46 of NBR 5410, according to the live conductor scheme) E. Temperature Correction Factor (Table 40 of NBR 5410) F. Grouping Correction Factor (Tables 42 to 45 of NBR 5410) G. Calculation of Corrected Design Current – I'B. After determining items A, B, C, D, E, F and G, tables 36, 37, 38 and 39 of NBR 5410/2004 are used to determine the appropriate conductor cross-section. The 3rd criterion voltage drop in an electrical installation, from the origin to the furthest point of use of any end-use circuit, must not exceed the limits established by NBR 5410/2004, in order not to impair the operation of the utilization equipment connected to the terminal or utilization circuits. The main limits between the sections vary: Transformer/Generator-Final Load: 7%, Delivery Point-Load 5% and Panel-Load 4%. To calculate the conductor cross-section based on the distance of the loads and the percentage allowed in each section, a formula can be used that finds a cross-section value, and according to the conductor cross-section tables assign the largest cross-section closest to it. Formulas omitted due to page limit.

The 4th criterion is overload coordination and according to the standard, there must be coordination between conductors and the protection device, in order to satisfy the following two conditions: 1. IBINI'z 2. I21.45 I'z. Where: IB = circuit design current (A) (without temperature and grouping correction factors); IN = nominal current of the protection device (A); I'Z = corrected current carrying capacity of the conductors, according to tables 36 to 39 of NBR 5410 (apply the temperature and grouping correction factors: I'Z = IZ x (FCT x FCA); I2 or Ia = conventional actuation current of the respective protection device. Current that effectively ensures the actuation of the protection device. (I2 = αIN). With these values in mind, one should look for protections (generally thermal-magnetic circuit breakers) that meet the nominal and overload currents, and if they are not within the range of the conductor, it is necessary to increase the conductor gauge and look for a circuit breaker with a larger In. In the 5th criterion, protective devices must be provided to interrupt all short-circuit current in the circuit conductors, before the thermal and mechanical effects of this current can become dangerous to the conductors and their connections (NBR 5410, 2004). According to the standard, one should know: 1. ICC or IK: The assumed short-circuit current at the point where the protective device is to be installed (calculation omitted due to document page limit) - circuit breaker or fuse - (A) 2. ICN: The nominal breaking capacity of the protective device (A) provided by the device manufacturer; 3. θCC: The short-circuit temperature of the conductor; 4. The conductor material (Cu or Al); 5. Tdd: Trip time of the protective device for the ICC value (s), extracted from the graph with the time x current curve of the device; 6. t: Limit time for actuation of the protective device (s), calculated according to equations; 7. Recommendations: a) The protective device must have a breaking capacity (ICN) compatible with the assumed short-circuit current (ICC) at the point of its installation. ICN ≥ ICC.

2.4 Single-line diagram

As required by standard (NBR 5410/2004), every electrical project must present at least one single-line diagram in addition to the floor plan, which represents the panels, circuits, busbars, protection stations and measurements. As also described by João Mamede Filho in Industrial Electrical Installations, in order to understand the operation of an industrial installation, it is essential to prepare a single-line diagram, which must represent at least the following elements: Fuse switches, disconnectors and circuit breakers with their respective nominal and interrupting capacities, as well as current transformers and cables; Indication of the cross-section of the conductors of the terminal and distribution circuits and their respective types (by phases); Dimension of the cross-section of the busbars of the distribution panels; Indication of the nominal current of the fuses; Indication of the adjustment currents of the relays, the adjustment range and actuation point.

2.5 Sustainable approaches in industry

When it comes to the electrical sector, designers could contribute to greater efficiency and sustainability in the industry by developing electrical projects that are environmentally conscious. In the article “CHALLENGES IN APPLYING SUSTAINABILITY IN THE BRAZILIAN ELECTRICITY SECTOR”, (Amanda Lange, Iuna Pinheiro and Luciana Londero, 2019) they describe that for the industrial sector, the main change to overcome sustainability challenges is to develop sustainable industrial plants to minimize energy and water consumption and the emission of effluents that cause the greenhouse effect. Therefore, the project presented here seeks to work with such objectives. Some example approaches would be: Sizing a capacitor bank to correct the power factor; because the company spends a lot of electricity unnecessarily, it is also fined if it exceeds the concessionaire's limits (ANEEL, Resolution 1000/2021); It is interesting to avoid sizing the conductors using the voltage drop method, which is based on distance and percentage voltage drop, where it is easy to use fewer conductors by reducing the distance between the load and its power supply point; In addition, it may also be possible to suggest more efficient materials, such as LED lamps, among others with greater efficiency; The performance of the inserted electric motors can be analyzed, and according to the standard (NBR 17094, 2018) the minimum value of the motor can be found.

2.6 Software development

Python is a very versatile object-oriented programming language. Based on C++, but with a more playful and direct syntax, Python allows the development of websites, software, systems, data analysis, machine learning and artificial intelligence, among many others. With a functioning based on variables, lists, dictionaries, functions, and classes, the language will serve as the basis for the program developed here. “PySide6” is a very complete framework used when it comes to developing interfaces for Python programs. Developed by the Finnish company QT Group, “PySide6” presents several ready-made and advanced interfaces that can be easily created using class logic. Examples of “PySide6” interfaces would be choice boxes, text boxes, list widgets, graphical views, among many others. (QT Group, 2022). Furthermore, PySide6 allows the modeling of interfaces in a program called QT Designer, which is visually very intuitive to speed up the development of interfaces in the current program, returning a class in “ui” format that can be recompiled in python format in CMD, and used in software programming (PyAutoGuis, 2024). Another important point that led this framework to be used is its freedom of license, which can be both commercial and open source, being met by both LGPLv3 and GPLv3 (PyPI, 2024).

3. METHODOLOGY

3.1 Research stages

The methodology and development of the current research is divided into 6 main stages in addition to the research plan, which are theoretical basis, software development, testing with validated projects, testing with end users, data analysis and final report. The theoretical basis will be a general and comprehensive review of the main processes involved in the development of a low-voltage industrial electrical project. In this stage, standards, books, existing software and materials related to the area will be reviewed, in order to deepen the knowledge and information of the research on the subject. To support the basis, interviews were also conducted with 6 engineering companies to understand how industrial electrical projects work in practice and what methodologies are used. In the software development stage, the proposed work will be developed using object-oriented programming in the “Python” language. After completing these stages, tests are planned to evaluate the performance of the software. In these tests, projects already developed and validated will be dimensioned, in order to find points for improvement, and a report of the results obtained will be developed. After this, tests with students and professionals in the area will be carried out, in order to analyze the practical use.

3.2 Preliminary interviews with companies in the electrical projects area

Interviews were conducted with electrical design companies at the beginning of the research to validate the idea of software development. These interviews served to understand the process of dimensioning industrial electrical installations in practice, as well as to understand what can be improved by software. Forms and face-to-face meetings were carried out with a total of 6 electrical engineering companies. In these interviews, the following questions were asked:

- Q1: What are the main loads that your sizing considers in an industrial electrical project? Q2: What are the biggest challenges faced when sizing an industrial electrical project? Q3: Do you use any software tool or process to facilitate the calculation and sizing of loads? If so, which one? Q4: What limitations do you find in these software tools that, if resolved, could further facilitate the sizing process? Q5: Would an automated industrial single-line electrical drawing also be useful in the project? Q6: What standards and regulations does the company follow when sizing low-voltage industrial electrical projects?

With the answers obtained, it was possible to analyze the electrical projects market and find out where help can be provided with software development. It was noted that few companies use software to develop industrial electrical projects, either because they are unfamiliar with or do not consider the existing programs to be practical. Those that do use it also see certain points that can be worked on, as described in Q3 Q4. Considering the answers, the objective for the current work can be established to develop electrical project software that: Generates single-line diagrams in CAD instantly; Is simple, intuitive and practical; Analyzes the inserted circuits so that they present less expenditure on materials and energy.

3.3 Software development

The software currently being developed uses the Python programming language. Microsoft's Visual Studio Code is used to organize folders. The Qt Designer program, integrated with the “PySide6” framework, is used to model interfaces. GitHub was used to version the code, where a repository called “TCC_-_Dim._Auto._Circuitos_Industriais” was created. Some folders were organized in it, such as “Projeto_Eletrico”, “Interfaces” and “Resources”. To implement the interfaces of the software developed here, the PySide6 framework and QT Designer were used together, which allows greater versatility for creating interfaces. To create an interface, the student models it in QT Designer and saves it in the “ui” format. The interfaces developed so far are described and presented below. The main interface in the program has a QMenu menu at the top with the options “File”, “Edit”, “Summary” and “Help”. A QToolBar taskbar was also created with the main functions of the project. The central widget is “QTabWidget”, with the “Load Table” and the “Single-Line Diagram”. In addition to the main interface, other interfaces were also modeled for the operation of the project, but they will not be described due to the page limit. For the cross-section calculation, a class called “CircuitSectionCalculator()” was created in the “Calculations” folder, which receives all the values needed to calculate the cross-section of a circuit, some of which are: LoadType, Voltage, Phases, Length, etc. The class already covers the 5 sizing criteria. In the “protection.py” file of the cross-section calculation files, the “Circuit Breaker” class was created, where a thermomagnetic circuit breaker is sized based on the following factors: Conductor current (Iz), design current (Ib), circuit voltage, number of phases, short-circuit current, and class of the circuit being sized. Based on the calculations already made, the software allows you to generate an Excel memory of the project's dimensions. The memory is based on the following structure: 3 tabs, one for project data, another for the cross-section calculation, and another for the capacitor bank. The project tab contains information such as the name of the project/client, desired/calculated power factor, largest cross-section used, demand, etc. In the cross-section calculation, the data for the 5 dimensioning criteria are arranged in 5 blocks of lines, and the circuits are arranged vertically. In the “Calculation Memory” button, the user chooses which memory to generate, and the “generate_memory” method of the “Electric_Project” class, together with the “openpyxl” library, is manipulated and an .xlxs file is created with the calculation values.

3.4 Single-line Diagram

To generate a single-line diagram, the drawing can be saved in a DXF file, and the user can view it in a graphical view of QGraphicsView from PySide6. The diagram is generated by the method of the class “draw_all()” that positions the items in the scene according to the project values. Currently, the symbology used in electrical projects is free, so it was chosen to use the most common standard (NBR 5444), but this is not a rule. To view the single-line diagram generated within the DXF file in the selected path, a class “DXFViewer” was created with a QGraphicsView from PySide6 as its parent class.

3.5 Sustainability algorithm

To check the sustainability of the project, a function was first created in a separate file called “sustainability.py” in the same folder as “calculus”. It receives only the circuit to be analyzed as a parameter and checks what can be improved in it, returning nothing if it finds nothing unusual, or a text explaining what can be improved in the object. In each main calculation class, the function “verificar_sustentabilidade” was created, which uses an instance of this class to check what can be improved. In the electrical project, this function is activated every time the project is dimensioned. An example of a point checked was the case of the conductors being dimensioned by voltage drop in a circuit. If this occurs, the program will calculate at what distance/percentage voltage drop the circuit needs to be in order to calculate the cross-section of the conductors by the 2nd largest cross-section, since a simple change in distances avoids the waste of copper/aluminum and PVC/XLPE conductors. Below are the formulas used to arrive at this value in the three-phase case:

$$MC3 = \frac{MS2*(QT(\%)*Un(V)}{100\sqrt{3}*p*In(A)} \quad (35)$$

Fonte: O autor, (2024).

$$MQT3 = \frac{100*\sqrt{3}*p*In(A)}{MS2*Un(V)} \quad (36)$$

Fonte: O autor, (2024).

- MC1 = Shortest single-phase length; MC3 = Shortest three-phase length; MQT1 = Largest single-phase voltage drop; MQT3 = Largest three-phase voltage drop; Un = Nominal circuit voltage in Volts; p = Conductor material constant; QT = User-allowed voltage drop; Comp. = User-entered length.

Another important point is the energy that can be saved by using higher-efficiency motors. It is necessary to establish a minimum value considering power, class, efficiency and number of poles. For this, two tables of minimum efficiency present in ABNT NBR 17094 were used, which establishes minimum efficiency of motor manufacturers according to their class (IR2 or IR3/higher), poles and power in kW. Another comparison made by software is in lighting circuits where LED lamps are suggested.

4. RESULTS AND DATA ANALYSIS

In the first stage of results testing, examples of industrial electrical projects were dimensioned within the software to compare the similarity of the results, and at which points the software was able to improve the sustainability of the projects. In the second stage, the software was demonstrated to engineering companies in the technical area and its effect on the development of electrical projects was questioned. The data were analyzed qualitatively and descriptively in order to confirm the use of the program by the target audience.

4.1 TESTING WITH VALIDATED PROJECTS - EXAMPLE OF APPLICATION IN INDUSTRIAL COMPLEX

The eighth edition of the book “Instalações Elétricas Industriais” by João Mamede Filho contains a rich example of application and dimensioning of industrial electrical circuits in an industrial complex, with 65 circuits, 15 distribution panels, a private transformer, a capacitor bank, and generating a single-line diagram. Due to the page limit, the test presents only 22 circuits, approximately 1/3 of the total.

4.1.1 PROJECT INPUT INFORMATION

This is an Industrial Manufacturing Complex, with driving, socket and lighting loads. The supply system of the supplier company has the following characteristics: 1. Nominal voltage: 13.8 kV, Supply voltage: 13.8 kV, short-circuit power at the industry supply point (delivery point): 176.5 MVA, secondary network voltage: 220/380 V.

Table 1 - Driving load of the industrial installation

	Sector	L Load	Nº Motors	Pot.(CV)	In (A)	Power Factor	Efficiency	Ip/In
CCM1	Batedores	5	2	30	43,3	0,83	0,9	6,8
CCM1	Cardas	30	6	7,5	11,9	0,81	0,84	7

CCM2	Cortadeiras	25	6	5	7,9	0,83	0,83	7
CCM2	Manteiras	26	9	3	5,5	0,73	0,82	6,6
CCM3	Passadores	20	7	10	15,4	0,85	0,86	6,6
CCM3	Encontreiras	17	3	5	7,9	0,83	0,83	7
CCM4	Central de Climatização	10	2	250	327,4	0,87	0,95	6,8

Fonte: MAMEDE, João, (2017).

Table 2 - Load chart light distribution

QDL's	Circuit	Load Type	Poles	Amount	Power (W)
	7	Ilumination	1	7	700
	8	Ilumination	1	7	700
	9	Ilumination	1	7	700
	10	Ilumination	1	7	700
	11	Ilumination	1	7	700
	12	Ilumination	1	7	700
	16	Electrical Outlet	3	6	6000
	17	Electrical Outlet	1	8	100
QDL2	18	Electrical Outlet	3	-	6000
	19	Electrical Outlet	1	15	100
	20	Electrical Outlet	1	12	100
	21	Electrical Outlet	1	68	40
QDL3	22	Electrical Outlet	1	64	40
	23	Electrical Outlet	1	36	40
	24	Electrical Outlet	1	36	40
QDL4	25	Electrical Outlet	1	1	1900

Fonte: MAMEDE, João, (2017).

4.1.2 RESULTS AND COMPARATIVE ANALYSIS OF CALCULATIONS

4.1.2.1 Results of the 5 sizing criteria

The cross-section defined in the circuits was generated by software using Excel. Next, the values found in the calculation of the conductor cross-section are compared. The main calculated information is highlighted in the table, with “Prog.” being the program values and “Livr.” those from the books. Certain repetitive data was also omitted.

Table 3 - Comparison of cross-section calculations - Socket/lighting circuits

	Método	IB(A)	I'B(A)	Seç. 2º mét.	QT calc. (%)	Seç. 3º mét.	In Disj.	Icc (kA)	Ir disj.(kA)	Tsc (s)
QDL-2	Prog.	95,4	212,1	120	0,8	25,0	180,0	7.99	8,0	3.37
	Livr.	95,4	212	150	-	25	28	9,8	8	-
C-16	Prog.	60,77	75,9	25,0	0,4	25,0	180,0	7.99	20	0.14
	Livr.	60,7	75,8	25,0	-	25,0	100,0	9,8	4,0	-
C-17	Prog.	4,04	4,04	2,5	0.49	2,5	4,4	7.99	3,5	0.0014
	Livr.	4,0	4,0	2,5	-	2,5		9,8	4,0	-
QDL-3	Prog.	13,47	25,09	4	1,14	2,5	15	0,814	4	0.314
	Livr.	13,4	25,7	4	-	2,5	15	0,81	4	
C-19	Prog.	7,57	7,57	10,0	1,0	1,5	10,0	0.7145	3,5	0.12
	Livr.	7,5	7,5	10,0	-	1,5	10,0	0,72	3,5	-
C-20	Prog.	1,8232	10,0	2,5	0,3	0,5	10,0	0.7145	4,0	0.122
	Livr.	1,8	10	2,5	-	0,5	10	0,72	4	
C-21	Prog.	13,73	17,17	1,5	1,1	1,0	15,0	0.7145	3,5	0.044
	Livr.	13,7	17,2	1,5	-	1	15	0,72	3,5	
C-22	Prog.	12,92	15,0	1,5	1,4	1,5	15,0	0.7145	3,5	0.044
	Livr.	13	15	1,5	-	1,5	15	0,72	3,5	
QDL-4	Prog.	7,56	14,54	2,5	0,7	0,75	10,0	0.84	4,0	0.114
	Livr.	8,0	15,3	2,5	-	0,75	10	0,84	4	
C-23	Prog.	7,27	10,0	1,5	1,0	1,0	10,0	0,78	3,5	0.041
	Livr.	7,2	10	1,5	-	1	10	0,78	3,5	
C-24	Prog.	7,27	10,0	1,5	1,0	1,0	10,0	0,78	3,5	0.041
	Livr.	7,2	10	1,5	-	1	10	0,78	3,5	
C-25	Prog.	9,5	10,0	2,5	0,3	0,5	10,0	0,78	3,5	0.114
	Livr.	9,5	10	2,5	-	0,5	10	0,78	3,5	

Fonte: O autor, (2024).

Table 4 - Comparison of cross-section calculation values - Driving loads

	Dim.	IB(A)	I'B(A)	Seç. 2º mét.	QT calc. (%)	Seç. 3º mét.(mm²)	In Disj.	Icc (kA)	Ir disj.(kA)	Tsc (s)

CCM-1	Prog.	158,8	352,98	400,0	0,140484	10	200	15.21	20	8.810
	Livr.	158	351,1	400	-	10	200	32,1	100	
M-1	Prog.	44,9	44,9	10	0,09684	1	6,0	15.21	15,4	0.0055
	Livr.	43,3	43,3	10	-	1	200	25,3	20	
M-2	Prog.	11,5	20,18	2,5	0,311327	1	25,0	15.21	15,4	0.0003
	Livr.	11,9	20,8	2,5	-	1	200	25,3	20	
CCM-2	Prog.	99,13	220,29	150	0,508485	16	25,0	11.1321	10,0	2.92
	Livr.	96,6	214,6	150	-	16	200	15,4	20	
M-3	Prog.	8,1	18,03	2,5	0,241887	1	25,0	11.1321	10,0	0.0008
	Livr.	7,9	17,5	2,5	-	1	200	15,4	20	
M-4	Prog.	5,6	12,5	2,5	0,243	0,75	25,0	290,0	10,0	0.0008
	Livr.	5,5	12,2	2,5	-	0,75	200	15,4	20	
CCM-3	Prog.	131,4	292,06	240	0,5	25	25,0	10,2908	10,8	6.43
	Livr.	131,5	292,2	240	-	25	200	14,6	20	
M-5	Prog.	15,29	28,32	4	0,6	1,5	50,0	10,2908	10,8	0.0017
	Livr.	15,4	28,5	4	-	1,5	200	14,6	20	
M-6	Prog.	8,11	11,59	2,5	0,2	0,75	16,0	10,2908	10,8	0.0006
	Livr.	7,9	11,2	2,5	-	0,75	200	14,6	20	
CCM-4	Prog.	676	1503	4x400	0,4	35	150	10.2908	10,5	29.47
	Livr.	654	1445	4x400	-	35	800	24,7	40	
QGBT	Prog.	2279	2331,5	6x300	0,2	25	2500	17.64	125	15.79
	Livr.	2278	2278	6x300	-	25	2x1200	32,1	125	

Fonte: O autor, (2024).

After analyzing each case, it was noted that there were practically no errors on the part of the software, only differences in the sizing methodology. Below are comparative tables regarding the similarity of the results and the accuracy of the software.

Table 5 - Comparison of design software accuracy

Value compared	Circuits with correct value	Total number of circuits	Accuracy (%)
Ampacity cross-section	65	65	100
Voltage drop cross-section	65	65	100
project current	65	65	100

Source: The author, (2024).

Table 6 - Software project similarity comparison

Value compared	Circuits with correct value	Total number of circuits	Similarity (%)
Ampacity cross-section	64	65	98,4
Voltage drop cross-section	63	65	97
project current	65	65	100

Source: The author, (2024).

4.1.3 SINGLE-LINE DIAGRAM COMPARISON

The single-line diagram was similar to the one presented in the example in the book in question. The panels and protections are arranged in an organized manner, with their respective nominal values, a disconnect switch and molded case thermomagnetic circuit breaker for each MCC, a thermomagnetic circuit breaker for QDLs, a thermomagnetic circuit breaker and contactor for each motor, the QGBT circuit breaker, and the transformer with its nominal value. It is represented from the transformer, through the meter, QGBT, MCCs to the motors and terminal circuits. The biggest difference is the size of the drawing, which in the application of the book is reduced to fit an A1 sheet, something that can be worked on in the future in the program.

4.1.4 SUGGESTIONS FOR SUSTAINABILITY AND IMPROVEMENT IN THE PROJECT

When this project was sized in the software, several suggestions for improving the sustainability of the circuits appeared. Among them, the main ones were voltage drop, efficiency and motor power factor.

Starting with conductors, a total of 14 circuits were sized by voltage drop. Below is the list of conductors used before and after these suggestions, as well as the amount of CO2 that will be saved by making this change, considering that 1 kg of copper is equivalent to an average of 3 kg of CO2 emitted (GOV, Ministry of Science, 2023).

Table 7 - Comparison of Drivers' Economy - Sustainable Suggestions

Circuit	Cross-section (mm²)	Length (m)	Weight (kg)	New c-Section (mm²)	New Length (m)	Weight after (kg)	Spared copper (kg)	Spared CO2
1 a 12	16	53	22,79424	6	29	4,67712	217,40544	652,21632
31	6	35	5,6448	2,5	19	1,2768	4,368	13,104
32	6	35	5,6448	2,5	19	1,2768	4,368	13,104
TOTAL							226,14144	678,42432

Source: The author, (2024).

With this, it is concluded that the sustainability suggestions regarding voltage drop can save 226.14 kg of copper, and save the emission of 678.42 kg of CO2 if applied. Now, regarding the suggestions regarding energy consumption, the amount of energy spent in the project was compared with the conditions provided, and after making the suggested changes made by the software. It was considered that the nominal power of the motor in kW over the efficiency is its energy spent in kWh.

Table 8 - Comparison of energy saved with motor efficiency

Motor	Power (kW)	Effic. Before	kWh spent before	Efficiency After	kWh spent after
M1	22,08	0,9	24,53	0,924	23,90
M2	5,52	0,9	6,13	0,91	6,07
M3	3,68	0,83	4,43	0,9	4,09
M4	2,208	0,82	2,69	0,9	2,45

M5	7,36	0,86	8,56	0,91	8,09
M6	3,68	0,83	4,43	0,9	4,09
M7	184	0,95	193,68	0,958	192,07
M8	5,52	0,84	6,57	0,91	6,07
M9	11,4	0,86	13,26	0,93	12,26
M10	14,72	0,88	16,73	0,93	15,83
M11	22,08	0,9	24,53	0,941	23,46
TOTAL			305,56		298,36

Source: The author, (2024).

Comparing the difference in total cost between replacing the engines for higher kWh efficiency, we have 7.2 kWh saved in a period of 1 hour. Calculating this over a period of 1 month, for example, with a demand of 8 hours of continuous and simultaneous operation per day, in 30 days, we have a consumption of 1728 kWh less. This saving can also save the emission of 259 kg of carbon gas into the air. In the long term, this saving can pay for the difference in price between a low- and high-efficiency engine. Of course, each industry uses its machinery individually, and this energy demand can vary up or down depending on its use. But it is clear from this comparison of values that the program can reduce energy consumption in driving loads significantly just by suggesting the correct efficiency engine within the standard. In total, a saving of 937.42 kg of carbon gas was calculated, almost 1 ton.

4.1.5 ANALYSIS OF THE PROGRAM'S DIFFERENTIALS

Below is a comparative table of the differences between the Sustuni software developed in this work and other programs on the market.

Table 9 - Comparison of Sustuni differentials and other programs

	Sustuni	**DOC ABB**	**Simaris**	**Power Design**
Industrial Electrical Design	Yes	Yes	Yes	Yes
Instant Single-Line Diagram	Yes	No	No	No
Sustainable analysis	Yes	No	No	No
Commercial products sizing	No	Yes	Yes	Yes
Brazilian standards support	Yes	No	No	No

Source: The author, (2024).

4.2 TESTING WITH FINAL USERS

This stage describes the tests that were carried out with end users, divided between tests with students and with companies in the area.

4.2.1 TESTING WITH ENGINEERING COMPANIES

The software was presented and received feedback from a total of 7 companies that work with electrical projects, namely: E1: Filippon Engenharia; E2: EC PROJ SOLUÇÕES ELÉTRICAS; E3: Luminus Soluções Elétricas; E4: Instel Engenharia; E5: QSI Engenharia; E6: Serrano Automação; E7: Neodomi Engenharia. Some tests were performed in person, and others through an online form, as follows: The program was presented running through an executable. After presenting all the program's features and discussing it with the engineering professional to whom it was being presented, some questions were asked, as described below. The answers to each question are provided in Appendix A. By analyzing the answers obtained by interviewing the companies, it was possible to evaluate, in a more qualitative way, what the designers liked most, what could be improved, and what would make the companies use the program. The main qualities highlighted by the program were: Its general practicality; Simpler and more intuitive than others on the market; Sustainability suggestions; Speed in dimensioning and single-line diagrams. When analyzing and describing possible points for improvement in the program's operation, professionals in the area highlighted the following issues: Increased volume and clarity in dimensioning information; Generate load tables, material lists, and provide information on manufacturers of dimensioned materials; Allow designers more freedom to change information in the project; Expand the types of projects that the software can dimension, in addition to industrial ones. The suggestions for improvements were of great help to the student in outlining what can be improved later in the software. Regarding the single-line diagram, all companies stated that the file generated by the software is of great help and usable in a practical context. Regarding improvements in the diagram, it was suggested that the user be asked for additional points such as DPS/DR, add the type of bus cable, among other more specific identifications so that the diagram is more finished. Considering the program's objectives, and also reviewing the interviews conducted at the beginning of the year regarding the demands of the project area, it can be concluded that the software achieved its objectives and differentiated itself in the market by meeting the following points: Greater interactivity and practicality; Automatic Single-line Diagram; Intelligent analysis to reduce energy expenditure and monetary costs; Support for Brazilian standards; Automation in the generation of tables for the memorial.

4.2.2 TESTS WITH STUDENTS IN THE TECHNICAL FIELD

The software was tested with 89 students from 4 different classes of the Electrical Engineering Technician course at Fundação Liberato, in the fourth and third years. It took place in the school's computer labs, where the software was installed on the computers and used by the students. The demonstration consisted of 2 stages: the first was the manual calculation, in which 2 circuits were sized in different cases, until the calculation of the current carrying capacity.

After sizing manually, the students did so within the software and analyzed the results to check whether the manual sizing was equivalent. In addition, a single-line diagram and a calculation memory of the sized circuit were generated. After the demonstration of the software was completed, the students answered a form described in Appendix B. Analyzing P1's responses, it was possible to conclude that the software achieved 100% accuracy, correctly sizing all the calculated variables for the 89 users in both cases tested. When asked what they would use the software for, the vast majority of responses involved learning and developing tasks in technical subjects, whether in low-voltage projects or electrical installations, to understand how to solve exercises, generate calculation memories and single-line diagrams, to facilitate both the work as a student and the learning process. What they liked most was its practicality, speed, organization, simplicity, and suggestions for sustainability in the project. With these results, the researcher also had the opportunity to analyze several points for improvement in the program's functionalities or interface, such as a tutorial within the software for operation, a more user-friendly visualization of the results, and a single-line diagram for students who are not yet familiar with this type of software.

5. CONCLUSIONS

Considering everything that has been developed throughout this year of research, it can be concluded that it was possible to develop software that intelligently and sustainably designs low-voltage industrial electrical circuits in an efficient and innovative way. As described, the software already measures the cross-section of conductors and protections for the main circuits in a low-voltage industrial electrical installation, and allows the user to enter a cross-section size limit. Tests with electrical projects showed 100% accuracy in calculating the cross-section of conductors, providing great confidence in the tested program. A single-line diagram is generated in DXF format, which can be manipulated in CAD tools and viewed instantly. Sustainable suggestions such as less consumption of materials and energy appear when it is perceived that the project can be improved, and if applied, they effectively reduce the costs generated by an electrical circuit. After presenting the software to engineering companies in the area, it was concluded that the software achieved its objectives, being practical to use, consistent sizing, saving time for the designer, and facilitating processes that other programs do not handle, such as generating single-line diagrams and supporting Brazilian standards. The program also received positive feedback from 89 students in the technical area, presenting 100% accuracy in the tests performed, being considered practical, fast, objective and precise. As an academic work, it contributed to the area of electrical engineering by facilitating the study and application of electrical installations, in addition to finding and combining new possibilities for applying energy efficiency and sustainability in the industry. As a product, this work should continue to develop based on the users' suggestions for improvements, analyzing its commercial viability, and launching it as a differentiated option in the market.

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APPENDIX A - RESULTS OF INTERVIEWS WITH COMPANIES

This appendix describes the interviews conducted with Engineering Companies. The questions presented in the form were:

- Q1: What did you like most about the program? Why?
- Q2: What do you think could be improved in the software?
- Q3: After learning about the software's unique features, why would you consider using the Sustuni program?
- Q4: Does the software tested increase time efficiency for developing electrical projects? If so, in which areas?
- Q5: Is the software tested consistent with other electrical project development methods validated and/or used to date? If not, what would be the points for improvement?
- Q6: Is the single-line diagram generated by the software usable? What could be improved?
- Q7: Are the software's sustainability suggestions applicable in a practical context? How could they affect your project?

Below is a table of each company's responses.

Q1	Q2	Q3	Q4

Objectivity, practicality, quality results	Review calculation points to be worked on	Cogitaria usar com certeza diagrama	Sim, no diagrama unifilar, e na parte da sustentabiliade por eficiência
PRACTICAL, BUT SOME CHANGES NEEDED	CLEARER INFORMATION ON THE DIMENSIONS OF THE ITEMS USED AND INSTALLATION METHOD.	PRACTICAL	YES, INSERTION OF THE NECESSARY INFORMATION FOR INSTALLATION METHODS AMONG OTHERS
Sustainability suggestions, the calculations behind, mainly voltage drop/conductor sizing	Generate a load table by software in excel/dwf	Time optimization, a critical look at sustainability	Especially in the part of conductor sizing
The idea as a whole is very good. What pleased me the most is that the software is simpler and more intuitive than the ones I use on the market. It is the type of software suitable for simpler installations, in which it is not worth investing in a complete and expensive software. It can generate a good cost-benefit ratio.	To be a truly usable software on the market, it must present: load board, single-line diagram, multi-line diagram, bill of materials and allow me to modify standard configurations, such as cable characteristics, for example, in which I want to be able to specify the manufacturer. It would also be interesting to present a system of multiple measurements, since there are many electrical projects, apart from industrial ones. I understand that the focus is industrial, but it can be expanded.	Because it has a simple interface, it saves a lot of time (if it generates the other items, such as load boards, diagrams, lists, etc...). It's easy for someone without much training to start dealing with it.	After launching points and infrastructure, the details are very time-consuming. Software can help a lot in this.
The speed to size a circuit and generate a single-line diagram.	We don't understand how to adjust the powers of the Frames, only the circuits. For example: in one frame, I put only a lighting circuit of 1200W and the power of the frame of 144kVA. We tried to locate where these loads were and we couldn't find them.	To speed up the creation of single-line ones.	Yes, in the generation of single-line ones.

Ease of use and user-friendly interface	Flexibility and Extended Scope	Agility and reduction of project time	Yes, in the calculation and drawing of diagrams
Simple interface	Some parameters can be editable		Provides data for architecting MCCs and the like
Practicality: Takes into account the variables necessary to make a good dimensioning	More information on plant consumption for further analysis Consider Incident Energy Separation of calculation memory by load types Data entry as an option by excel	Practicality Agility Independence from other software	Brings a lot of reliability /Agility in obtaining results without the need to consult tables

Continued responses companies

Q5	Q6	Q7
Yes	Yes, put plant design information	Yes, you can branch to 2 types of modification, print in PDF
YES, COHERENT. HOWEVER, IT IS NECESSARY TO BETTER DEFINE THE INSTALLATION METHODS.	VERY FUNCTIONAL, INTUITIVE AND CORRECT, ABOUT IMPROVEMENTS GENERATE SHEET WITH COMPANY SEAL	YES
Yes	Yes, and it can be considered different symbologies of designers	Suggestions are applicable, would affect helping to analyze data and suggestions for improvements
It is coherent. What can be improved has been answered earlier.	It is usable. What could be improved is the identification of component characteristics, such as placing Icc and type of curve in the circuit breakers, DR and DPS option, neutral and grounding, placing the protective conductor in the lighting circuits (although it is not usually used, it is mandatory by the 5410 to have protection throughout the entire route of all circuits). Add the type of cable and busbar.	Suggestions are useful when combined with immediate savings. If the savings are for the long term, many customers are not interested. But for the designer it is very interesting.

We use prysmian's software to size the circuits and the methodology is very similar.	Yes. It would need to include whether the cable used is PVC or EPR.	I believe it will vary from case to home. For example: in the test I did it suggested changing the position of the QL by a few meters to reduce the feeder section, it is not always possible to do this, but in the cases that it does, it ends up being very interesting.
Yes	Yes. It should include the possibility of exporting in DWG format and creating labels for formatting the document.	Yes
I advise developing similar software for extra low voltage projects.	yes	
It would have coherence for sure	Okay, of changes: ask the user for extra points as DPS/DR and standardize the sizes	Yes, they are applicable to a certain extent while using less energy

APPENDIX B - RESULTS OF CLASS INTERVIEWS

This appendix describes the interviews conducted with students from the 3rd and 4th year classes of the Electrotechnical Technician course at the Liberato Foundation. The questions presented in the form were:

- Q1: Were the manually calculated values equivalent to those in the software? If it does not describe the other calculated value:
- Q2: As a student, for what purpose would you use Sustuni software?
- Q3: What did you like most about the software shown?
- Q4: Would you highlight any points of improvement in the operation or user experience of the program?

The answers according to each question are tabled below. Only 9 of the 89 answers were presented, as the answers are very repetitive and there is a page limit.

Q1	Q2	Q3	Q4
Yes	It is useful for performing activity checks and seeing if it is correct	Speed and precision	For me it's very good, if it were a little simpler to use it would be interesting
Yes	For correction and comparison of tasks	Practicality	No

Yes	For circuit design in installations	Practicality	No
Yes	I would use the software to learn, evaluate my impact, and participate in projects that promote more conscious practices.	Practicality in development	I liked the use of the program itself
Yes	For study in the field of electrical installations	The ease of generating the results of calculations that require time to be calculated.	No
Yes	To assist in my studies and learning about standards.	Practicality and simplicity of use.	No, I believe it is ready for use.
Yes	To help me in the matter of electrical installations	The functionality and practicality of using	No
Yes	with the help in the work of technical matters	the ease of calculating the circuits	I think it's very good
Yes	To calculate and check the calculations of facility designs.	The practicality and clarity of the information.	Placing conduits would be very useful too.

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1. The topic appears to be practical and suitable for local industrial needs.
2. In addition to describing the engineering process of this research work and some survey of other works, it would be good (also required) to present the innovation of this work. A comparison of the proposed system with existing state-of-the-art methods should be provided in the introduction so the advances, contributions, and novelty of the approach can be identified.
3. It would be good to include design philosophy to let the reader understand the methodology of this design.
4. Authors are advised to present the designed circuits generated by this software.
5. If Y-connection of 3Φ4W was used concurrently with Δ-connection, can the software consider the load balance between phases?
6. The function and specification of the software can be further elaborated. Does the software account for the in-rush current when appliances such as motors are required?

7. Furthermore, an experimental evaluation which combines both macro and micro-movements is suggested.