

Design of low voltage electrical circuits for industrial receivers

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Abstract. *The paper presents the creation of a software for designing, verifying and analyzing voltage drops on electrical circuits, taking into account the classic design formulas and also the reactance of low-voltage electric cables. With the help of the application, it is possible to dimension and verify the existing electrical circuits as well as those of the single-wire schemes being designed as a result of the modernization or replacement of equipment in existing distribution networks. The application can be used for designing general consumers or for electrical equipment operated with direct start, star-delta or frequency converter electric motors.*

Keywords: *software, application, dimensioning, design, electrical circuits, electrical networks.*

1. Introduction

The design and dimensioning of low-voltage electric circuits requires the knowledge of the electrical parameters of the loads (receivers) in order to choose the protection apparatus and establish the right section of the electric cables based on their behavior.

Most of the length of the electrical circuit is outside the electrical panel, but the protection must be chosen according to the type of load in order to be able to properly dimension the protection of the cables used, this is done in the dimensioning of the electrical panels.[1]

Most of the length of the electrical circuit is outside the electrical panel, but the protection must be chosen according to the type of load and the type of consumer in order to be able to properly dimension the protection of the cables used, this is done in the dimensioning of the electrical panels. Electric consumers are described by specific parameters such as: current, voltage, nominal power, power factor, starting current, peak current and other parameters that must be taken into account when designing and resizing electrical networks.



From the supply point to the consumer, the effective value of the voltage decreases, due to the reactance of the supply circuit, characterized by the electrical resistance but also by the inductive and capacitive components specific to each supply line.

In the activity of designing electrical circuits, there is a need to determine the section of the cables and implicitly check the value of the voltage drops for the power lines, values imposed by the regulations but also by the proper operation of the powered electrical equipment.

In order to properly dimension the insulated power lines, the losses due to the insulation and its aging must also be taken into account, as is also presented in the work [2]. [3].

In the design of electrical circuits, exceeding the recommended voltage drop values negatively influences the operation of powered equipment and generates energy losses, reducing the total efficiency of the installation without bringing any benefits. In the design and verification process, verification formulas are used that require compliance with the limits imposed by local regulations like in the formula number (1).

$$\Delta U \leq \Delta U_{ad} \quad (1)$$

To analyze the operation of electrical circuits, modelling and simulation can be done using various dedicated programs [3]. To model the electrical supply circuits, we use the balanced three-phase alternating current line both in the case of internal and external networks because the receivers are symmetrical by their construction or are symmetrized by equal charging of the phases. That's why the distribution lines are modeled by a simplified scheme that takes into account only one of the phases in which the total reactance is presented with the help of the total resistance R in series with the total reactance X, according to Figure 1.

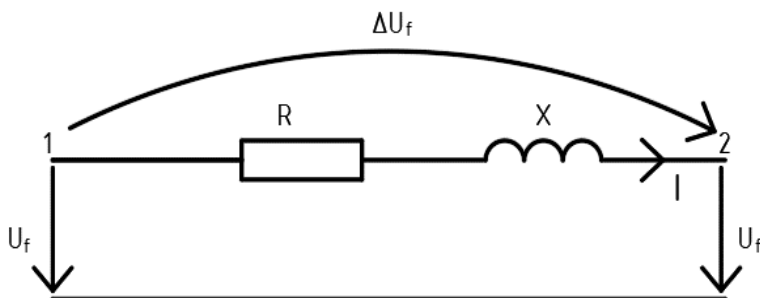


Figure 1. The typical model of a power line.

The voltage loss can be determined if the current through the respective line and the R and X parameters of the respective line are known using the formula (2, 3, 4)

$$\Delta U_f = RI \cos \varphi - XI \sin \varphi \quad (2)$$

$$R = \rho \frac{l}{s} = \frac{l}{\gamma \cdot s} \quad (3)$$

The electrical resistance parameter of a supply line R is determined based on the material characteristics of the conductors ρ used and the length of the respective line. For copper and aluminum cables, the conductivity values are $\gamma = 57$ and $\gamma = 34$, and "s" is the cable section.

The total reactance X of the line is calculated based on the data from the cable catalog sheets where it is described as the reactance per unit length.

The total reactance of the power line is distributed along the electrical cables, which helps to diagnose and detect damaged portions by using high-frequency sonar equipment as explained in the paper [4]

If the exact parameters of the line are not known or the data provided by the catalogs are not sufficient, then the unit reactance value can be approximated as $X_0 = 0.0001 \text{ } \Omega/\text{m}$. [5]

Substituting in the relation (2) the resistance and the reactance, the expression of the voltage drop for a three-phase alternating current line becomes one in which resistance and reactance are taken into account.

$$\Delta U\% = \frac{P \cdot l \cdot 10^5}{U^2} \cdot \frac{1}{\gamma \cdot s} \cdot (r_0 + x_0 \cdot \text{tg} \varphi) \quad (4)$$

If the real parameters of the cables to be used are not known from the design phase, the designer is forced to disregard the reactive components and take into account only the resistive component of the cables for the calculation of the voltage drop. (4)

During the course of the project, he can make any corrections especially for the longer lines after he makes a recheck of them right before the completion of the project.

$$\Delta U\% = \frac{P \cdot l \cdot 10^5}{U^2} \cdot \frac{1}{\gamma \cdot s} \quad (5)$$

To obtain the value of the relative error $\varepsilon\%$ we combine the two relations regarding the voltage drop obtained by the two methods, the one that takes into account the reactance of the cables and the one that does not take it into account. The obtained value can become significant for longer cables and larger sections.

$$\varepsilon\% = \frac{x_0 \cdot \operatorname{tg} \varphi}{r_0 + x_0 \cdot \operatorname{tg} \varphi} \quad (6)$$

For example, by adopting the permissible error $\varepsilon=0.05$ the sections of copper and aluminum cables expressed in Ω/m must satisfy the relations

$$s_{Cu} \leq \frac{9.93 \cdot 10^{-4}}{x_0 \cdot \tan \varphi} \quad (7)$$

$$s_{Al} \leq \frac{16.45 \cdot 10^{-4}}{x_0 \cdot \tan \varphi} \quad (8)$$

2. Example of application for the electrical design

A three-phase motor with the following nominal data is considered: power of 7.5 kW, power factor $\cos \varphi = 0.85$, line voltage of 400V.

The voltage loss between to the distribution board and the consumer where the circuit is made with copper cable with a section of 10 mm^2 and the circuit length l is 85m will be calculated in the following situations:

- a) Taking into account the inductive reactance of the cable
- b) Neglecting the inductive reactance of the cable.

First step is to calculate the specific resistance for the cable with a section of 10 mm^2 with the help of the next relation:

$$R_0 = \frac{1}{\gamma \cdot s} = \frac{1}{57 \cdot 10} = 0.175 \cdot 10^{-3}$$

Step two is to determine the specific reactance of the cable $x_0 = 0.1 \cdot 10^{-3} \Omega/\text{m}$

From the value of $\cos \varphi = 0.85$ corresponds to $\tan \varphi = 0.62$.

Step three is where we determine the voltage drop in the two considered situations with and without considering the influence of the inductive reactance of the cable. The voltage loss is calculated with the expression (4)

$$\Delta U\% = \frac{7.5 \cdot 85 \cdot 10^5}{400^2} \cdot (0.175 + 0.1 \cdot 0.62) \cdot 10^{-3} = 0.094$$

$$\Delta U\% = \frac{7.5 \cdot 85 \cdot 10^5}{400^2} \cdot 0.175 \cdot 10^{-3} = 0.069$$

The error is:

$$\varepsilon = \frac{0,069}{0.094} \cdot 100 = 26\%$$

The voltage drop obtained in this way falls within the limits allowed for normal operation and direct start-up of the verified electric motor type.

3. Description of the application

The proposed application is made using the Livecode Community Edition version 9 programming language, which allows the creation of rich and interactive graphical interfaces. Applications made with this programming language can be compiled directly without modification for other platforms such as Linux, Mac or HTML5. And with minimal changes it can be compiled for Android and iOS mobile platforms.

The developed application can be used for designing and checking three-phase electric lines based only on the behavior of the consumer connected to it.

The graphical interface of the application is intuitive and is based on a selection algorithm similar to the installation wizards, in which the user can choose one of the options available at a given time.

By choosing step by step different configurations the parameters and starting configurations are determined. The user must answer only the relevant questions about the configurations he choosed. The user is guided from the beginning to the result with precise steps being requested only the strict information necessary to configure the selected starting method.

When opening the application, we are greeted with a window that contains a brief description of the application and a series of buttons with which the user can navigate to the home page or to the previous page, as seen in Figure 2.

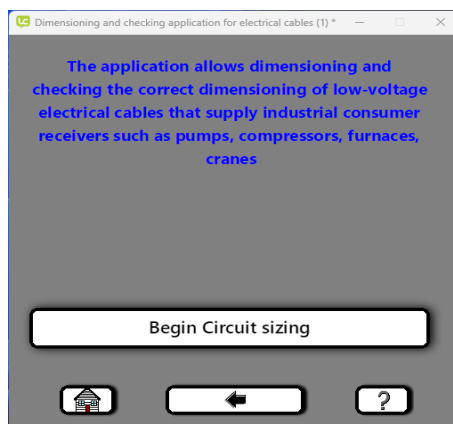


Figure 2. The welcome screen of the application.

In the following steps, the user will choose in small steps the desired drive type, the desired start type for the designed or verified application and then the nominal data of the drive motor of the designed equipment.

After entering all the necessary information according to the selected startup method, the application will determine the required theoretical section for the cable based on the entered data. After determining the corrected standardized section by the application, this new section is checked for the nominal regime, than for the starting regime. Checks are made both for the allowed current density and for the maximum allowed voltage drops in normal mode and in start-up mode for each section determined by the data supplied.

To exemplify the simple way of using the application, we will determine the section required for a three-phase power supply cable of a piece of equipment driven by a 7.5kW electric motor.

For this we will run the application where in the main window we will select the "Begin Circuit sizing" button, then from the displayed options we select "Classic electric drive" for direct start or star-delta as can be seen in Figure 3a.

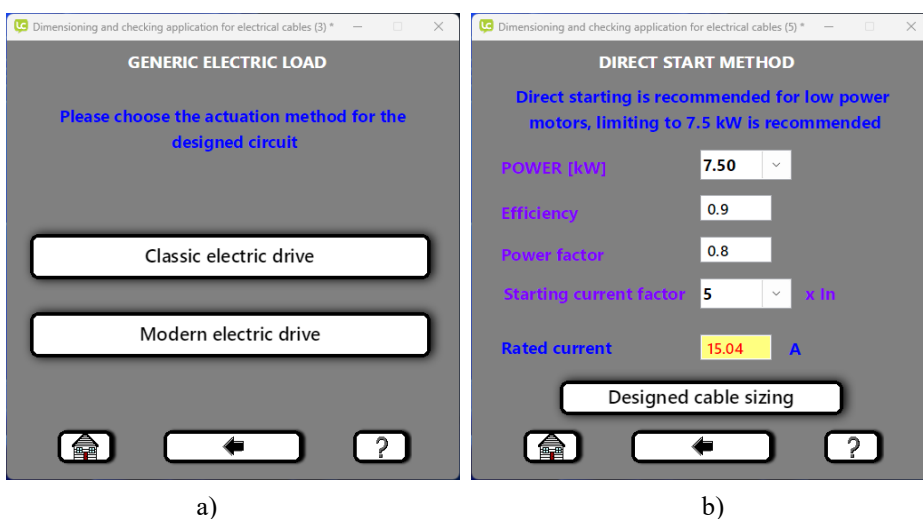
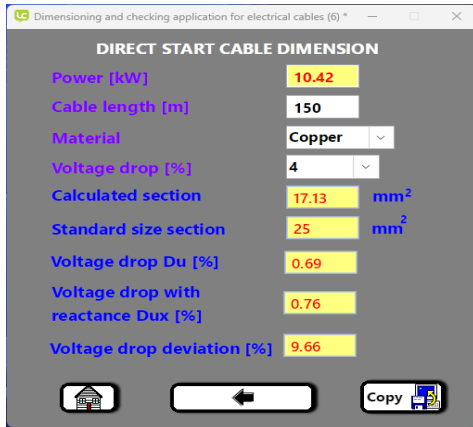


Figure 3. The page where you choose the drive method and motor parameters.

Figure 3b shows the area where the nominal parameters of the drive motor are entered, here the starting coefficient can also be selected depending on the actual starting regime of the application.



Starting method	DIRECT START CABLE DIMENSION
Power [kW]	10.42
Power factor	0.8
Length [m]	150
Material	Copper
Voltage drop [%]	4
Calculated section [m]	17.13
Standard section [m]	25
Voltage drop Du [%]	0.69
Voltage drop Dux [%]	0.76
Voltage drop deviation [%]	9.66

a)

b)

Figure 4. Calculation of the section and verification.

The following options clarify which of the two startup methods will be used in our project. The application recommends for powers of maximum 7.5kW the choice of direct starting method, but this is not mandatory.

After completing the information, we can press the "Designed cable sizing" button, which will redirect us to the final part of the cable sizing as seen in Figure 4a where we can select the length of the power supply circuit and the type of material it is made of. After establishing the parameters of the supply line we can impose a maximum voltage drop for the dimensioned circuit, a value between 1 and 10 % is allowed.

At any change made in every step the application calculates and checks a new section for the new data entered. If we want to return to some choices made, we can press the button symbolized by a black arrow, which will redirect us to the previous page as often as we need it, even to the home page. When returning to pages already visited, the information already entered is restored and we can resume the task with the new data or selections already made.

The final results of the application can be copied into the system's clipboard and after that pasted into a text editor or any word processor. The calculated values are returned in a tab formatted text as seen in Figure 4b.

4. Conclusion

The developed application allows the quick determination of the cable sections and its verification at voltage drop in normal mode and at start-up mode for electrical motors.

Compared to dedicated software, it has the advantage of calculating the electric circuit, without the need to describe the whole network from the power supply to the receiver.

The known data for the line parameters are entered manually or are selected from a list of predefined sizes of standardized powers to facilitate the operation.

The results obtained are validated by the application taking into account all the regulations and standards regarding the technical limits allowed.

The application allows the user to run multiple instances of the program to be able to simulate multiple scenarios side by side to compare the results obtained.

References

- [1] Protea B., Muscai C., Navrapescu V., Spunei E., Piroi I., Piroi F., *Computer assisted equipment selection for components of electric panels*, International Conference on Applied and Theoretical Electricity ICATE, 4-6 Oct., Craiova, 2018.
- [2] Preduș M.F., Spunei E., Roșu M., Prediction of power cables failures using a software application, *Studia Universitatis Babes-Bolyai Engineering*, 65(1), 2020, pp. 153-162.
- [3] Chioncel C.P., Spunei E., Anghel-Drugarin C.V., Piroi I., *Direct Self Control Structure for the Asynchronous Machine, Implemented in Scilab / Xcos*", 6th International Conference on Modern Power Systems, Cluj, 18-21 May 2015, Acta Electrotehnica, nr. 3, pp. 52-55.
- [4] Preduș M.F., Spunei E., Piroi I., Roșu M., *Diagnostic of Defects at Electric Lines in Cable*, Proceedings of 10th International Conference on Electromechanical and Power Systems SIELMEN 2015, Chișinău, 8-9 oct. 2015, pp. 518-521.
- [5] Piroi I., *Instalații electrice și de iluminat*, Editura Eftimie Murgu, Reșița, 2009.

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