Improving a CAD tool to simplify the design process of electrical schematics oriented to industrial-machine control

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Article Information

Abstract

Electrical circuits are graphically described most of the times and the use of some kind of computer-aided design (CAD) to do it is more than usual. Electrical engineers can be highly helped in this process with a library of symbols to represent the different components of a circuit and, wouldn't be interesting if they could simulate the circuits that they had graphically represented? We thought so.

For the previous reasons, a tool with just a good library of electrical symbols would be useful but, if it made possible to test the circuits it could have a great value, both for professional and educational purposes. This tool is really helpful in the learning process of our students in Technical Office. In this subject, the Electrical Engineering Degree students must work on an electrical project which always includes the design of some kind of circuit. The tool makes possible to simulate those circuits within the CAD software, so it is easy, fast and safe to try different designs by changing the graphical symbols and/or their connections.

Those features make the tool interesting in an educational environment, but not only. Professional engineers can also find this tool interesting because it can be used in the design process and as a tool for graphical representation. The improvements in the tool included, e.g., the wire simulation within the electrical box, making the circuit safer and cheaper.

1   Introduction

The software EleCirCAD has been developed by the authors, since 1990, to obtain a tool to be used in the design process of electrical schematics [1].

This tool has been conceived to help students to elaborate the technical drawings that define the electrical equipment used in their projects of industrial machines.

The obtained software, beyond its pedagogic philosophy, can also be used in general industry. Since the late 90's, this tool has been accessible to professional engineers and it has been downloaded more than 100,000 times from the EleCirCAD website [2].

The previous experience with this software, as part of the learning process of our students, has been really good. Taking into account that the Bologna Declaration on the European Space for Higher Education (ESHE) is a reality nowadays [3], it has been required to adapt the previous teaching methodologies and, as a consequence, to reduce the number of conventional classes in all the subjects to make possible the necessary convergence at European level. In this sense, the tool should be improved to make possible a higher level of self-learning and this is why we started to study how it influences the learning process.

The considered criterion is based on the analysis of the relation between our tool and the three cognitive abilities that can be considered the keys of a learning process: reasoning, operating and remembering [4].

Taking into account these three abilities, it can be considered their correspondence to the three stages in which the design process can be divided, as well as development of the documentation required to define the electrical equipment for controlling industrial machines.

The relationship between these abilities and the design stages is described below:

1.1   Reasoning ability: Functional design of schematics.

When students start designing a control circuit, they should relate the operating way of the different devices to satisfy the initial requirements.

Students know how those devices work and must be able to establish relationships between them and the input and output variables of the system. Students can do this by inserting components in the drawing and wiring them.

The results of this initial stage can be observed in the obtained circuit-schematics.

1.2   Operative ability: Switchgear and controlgear layout.

The next stage in the design process requires implementing the schematics within the machine. To solve this problem, a sequence of logical stages should be followed:
-   In a first place, it must be chosen the cabinet in which each component will be located.
-   A terminal has to be joined to every cable that connects elements from different cabinets [5].
-   All the inserted terminals have to be numbered following a coherent pattern [5], using prefixes to distinguish the different strips of terminals. All this information can be observed in the schematics of external-connections.

1.3 Remembering ability: Completing the schematics documentation.

To finish the process, it is necessary to develop some simple and repetitive work to include in the schematics all the complementary information that could be required. This includes numbering all the auxiliary contacts, tracing all the crossed references and drawing the legend.

At this stage the remembering ability has a high importance because it is necessary to have a good knowledge of the standards to be used in the development of schematics.

2 Innovative process of the improvement

As an application improvement process, it was considered to add simulation modules to be run alter finishing each design stage.

As Schneider and Fieg [6] reflected in a previous research, computer simulation provides a powerful tool for equipment and system analysis. As they followed: In fact, simulations are recognized as an efficient and effective method of teaching and learning complex and dynamic systems [7]. Some software and tools are being applied in educational environment with this purpose as published by Company et al. [8], Lau et al. [9], and Méndez et al. [10].

Using these simulators, students should be able to validate their work every time, increasing their curiosity to interactively carry out different experiments: "learning by doing" [11].

2.1 Functional design of schematics

After inserting components and wiring, students can simulate their operation using the same software.

Simulation process is not only based on the animation of the components of a circuit. In fact, a working-process diagram is automatically generated [12], [5].

This makes possible to appreciate the changes instantaneously and to analyze them globally, with all the diagram components.

Simulation can be cancelled at anytime, being able to modify the schematics and following with the simulation process.

2.2 Switchgear and controlgear distribution in the machine

The objective of this stage is to assign components to the cabinets in which they are located in order to be able to insert the required terminals to interconnect those cabinets.

The software automatically generates the external-connection schematics taking into account this information.

The most difficult aspect at this stage is found when a student is not able to appreciate the relationship between the circuit wiring and the information that appears in the connection schematics.

The developed improvement shows a simulation of the wiring that the student made in the circuit schematics as it would appear in the real machine. Thanks to this process, the schematics with the external connections can also be adjusted.

The software also displays valuable information about the most usual mistakes, such as cables interconnecting cabinets directly, without using terminals, too many cables connected to the same terminal, or duplicated cables, among others.

This simulation tool is based on the reading of the schematics wiring and the connection of terminals [13], [14], graphically showing the cable identifying information [15].

2.3 Final documentation of schematics

The final stage in the development of schematics takes into account the user requirements to define the sequence of commands. These orders must be correctly run to finish the schematics.

This can be considered a repetitive process, being just necessary to remember what are the commands used for and how they affect to the resulting schematics.

Finally, it is important to take into account that all the software development has been based on European standards [16], for numbering terminals, and [12] for complimentary information.

3 Case study

A simple case study has been included below in order to analyze the most important problems in the development and the modules added to the software.
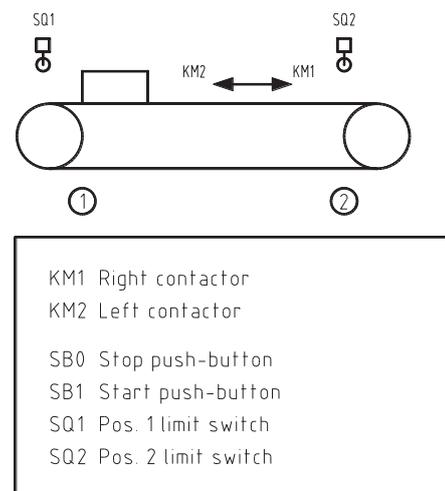

Fig. 1 Inital information of the case study

The case is based on the automation of a simple process: a table with two positions in which the mission is to send a piece from position 1 to position 2 and, finally, to go back to the starting point.

Variables are also assigned, by the tool, to unify results. The list of elements is included in fig. 1.

3.1 Design of schematics. Simulating the working process

Students have to start the design process analyzing the initial data and proposing the control circuit.

Attending to the initial data, the circuit is based on two reversing contactors. When the starting push button –SB1 is pushed, the contactor –KM1 is activated, sending the piece from position 1 to position 2. When position 2 is reached, the limit switch –SQ1 is activated, stopping –

KM1 and activating –KM2. Then, the piece goes to the starting position. When it arrives to position 1, -SQ1 is activated and the process ends.
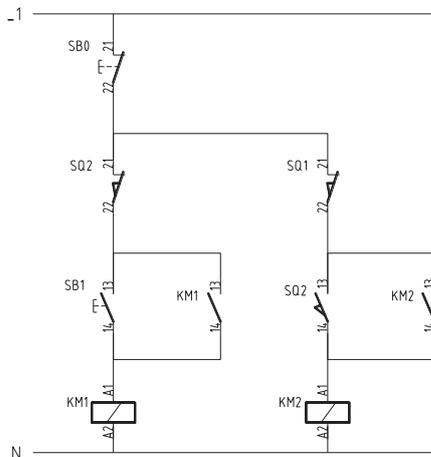
The easiest solution has been represented in fig. 2.

Fig. 2 Component insertion and wiring

Working process simulation:

One of the goals of this improving process was to allow students to test their designs. To achieve it, the simulation module was included within the software. This makes possible to transform the schematics into logical equations, to simulate the process, at any time. This is how students can check if their schematics are working as they expected, attending to the electrical specifications.

The working process diagram is automatically generated while the simulation process is developed and the positions of the contacts are displayed attending to the state of each component. The diagram obtained in this example simulation is shown in fig. 3.
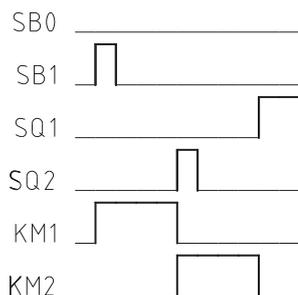

Fig. 3 Working process diagram

The use of this simulator during our practical sessions made possible to understand the developed schematics to more than a 90% of our students.

3.2 Component placement. Wiring simulation

The process of component placement requires several stages, as follows.

Assignment of switchgear and controlgear to cabinets:

Users have to indicate the cabinet that contains each component. The following figure shows how the switchgear and controlgear have been placed in the cabinet =C1 and the limit switches -SQ1 y -SQ2 have been placed out of the cabinet, represented as =CE.
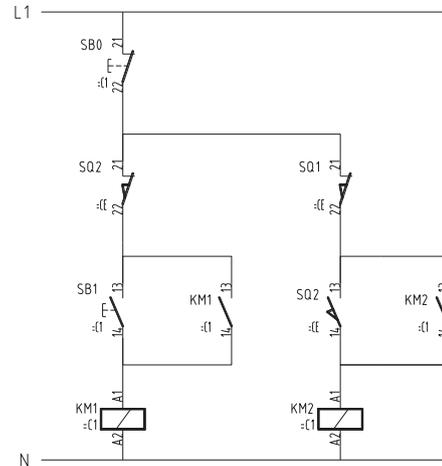

Fig. 4 Cabinet assignation

The layer with the attribute of component situation has been maintained activated (fig. 4) in order to make this stage more understandable.

Insertion of terminals:

It is necessary to place the terminals on the cables used to connect elements that are placed in different cabinet [5]. The software lets the user identify the cables that are requiring the insertion of terminals and this is the most difficult stage. The software can only detect the cables on the drawn schematics. During the design process, users have typically been involved in how the schematics are working without taking into account the most correct places for the machine components. This procedure implies that the inserted terminals are not optimized to obtain the most correct wiring in the machine. The real problem is that users are not able to intuitively notice this aspect, being necessary to automatically generate the external connection scheme.

Numbering of terminals:

This process is automatically done by the software, making possible to group the terminals creating strips. The software groups the terminals attending to the interconnected cabinets and the user assigns a prefix that is related to the name of the strip of terminals.

This is the stage where errors start to be detected. For example, users can notice terminals that interconnect elements within the same cabinet or even interconnecting elements simultaneously placed in three different cabinets. During the numbering process, it is interesting to adapt the wiring in order to solve these errors.

The figure below shows how all the indicated terminals are interconnecting elements contained in the cabinet =C1 with the limit switches placed outside: =CE. All of them have the same prefix (-X1) because they are integrated in the same strip of terminals.
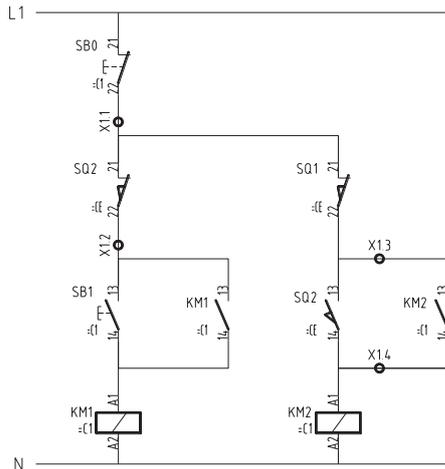
Fig. 5 Inserted and numbered terminals

Generation of the external-connection schematics:

When there are connections among different cabinets, it is compulsory to generate the external-connection schematics [5]. The software generates it automatically by means of the information that can be read from the circuit schematics.
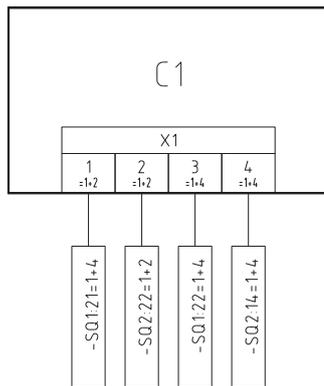

Fig. 6 Schematics of external connections

These schematics are very important for the machine maintenance and they must correspond to the developed design. Students are not usually able to interpret the mistakes that appear at this stage of the process due to their difficulties to establish relationships between the schematics and the wiring in the circuit. This is why the new version of the tool includes a wiring-simulation module.

Wiring simulation: It makes possible to generate an image of all the switchgear and controlgear contained in the machine. This image is automatically generated from the information that the circuit schematics contain. To facilitate the wiring understanding, the software traces the cables using a colour code:

- Blue cables connect elements within the same cabinet.
- Magenta cables connect terminals placed in different cabinets.
- Cyan cables connect terminals of a cabinet with external elements, such as limit switches.

An important feature of this software is that it graphically warns the user when errors are detected: Yellow lines indicate wrong cables and coloured rings are

traced when more than two cables are found in a terminal.

The fig. 7 shows the graphical representation of the wiring simulation corresponding to the previous circuit. Errors can be easily seen, so users can modify the circuit schematics, where cables and terminals are conveniently identified. It is recommended to number all the cables previously in order to make their identification easier.
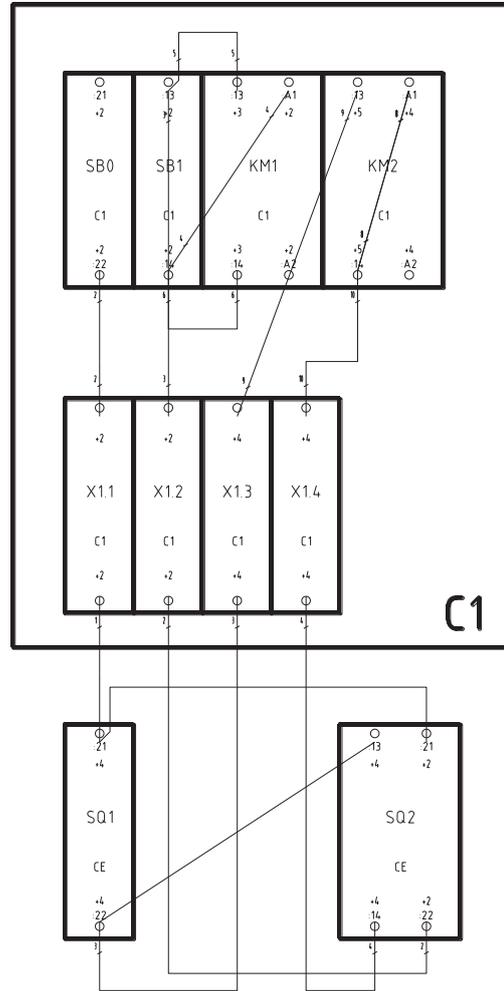

Fig. 7 Wiring simulation

This module was implemented during the current course. It made possible to appreciate how the percentage of students that were able to wire the circuit schematics and make the external connections, correctly and without any external help, was 80%, instead of the previous 50% without using the simulator.

4   Conclusions

1.- When a simulation module is added to a graphical software to design schematics, the learning process of students is clearly improved. As students learn by doing, they improve their skills with this software and also automating concepts.

2.- As it is possible to simulate how the schematics work, this improved process avoids design errors that would affect to subsequent procedures. This improvement reduces the previously required time to repeat mechanical actions without contributing to the actual learning process.

3.- The wiring simulator enhances how students assimilate the relation between the circuit schematics and their physical implementation. It also reduces the number of wiring mistakes that students will make.

4.- Including the wiring simulator gave us one more opportunity to improve the software. After analyzing the results of simulation, students start to think how to optimize the schematics wiring taking into account how the switchgear and controlgear in the cabinet is relocated.

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