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Teaching using a synchronous machine virtual laboratory

John Ramírez-Romero†, Diego Rodriguez†‡ & Sergio Rivera†

Universidad Nacional de Colombia, Bogotá, Colombia†
Consulting Engineers (GERS), Weston, FL, United States of America‡

ABSTRACT: The National University of Colombia in Bogotá, Colombia, has developed a virtual laboratory for synchronous machines (VLSM), which is important, because synchronous machines are used for the majority of electrical generation. The VLSM forms part of a bigger structure, and that is the Electrical Machines Laboratory. The objective of this work was to present and discuss the characteristics of the VLSM and the strategy for evaluating the performance of it. The evaluation involves a comparison between two groups of students, one of which uses the virtual laboratory and the other takes classes in the traditional way.

Keywords: Virtual laboratory, synchronous machine, optimisation, simulation

INTRODUCTION

The Vicedecanatura of Research and Extension of the National University of Colombia (responsible for the promotion of scientific research in the Faculty of Engineering) [1] and the Academic Office in Bogota approved financing in 2018 for the development of a virtual laboratory for synchronous machines. Although the development of it was intended mainly for students and teachers of the Electrical Machines Laboratory of the Institution, it is available to any person or institution.

The Electrical Machines Laboratory of the National University of Colombia in Bogotá mainly consists of devices used in industrial settings (mostly rotating machines) and a power system that provides power and protection to users [2][3]. Specifically, in this laboratory, four types of electromagnetic conversion devices are used: transformers, induction machines, DC machines and synchronous machines.

Virtual laboratories of induction machines and electric transformers previously were developed to prepare students for engineering practice [2][3]. In this article, the development of the Virtual Laboratory of Synchronous Machines (VLSM), the characteristics of it and evaluation, is presented. A comparative educational performance evaluation was carried out between two groups of students, one of which used the virtual laboratory, while the other was taught in traditional classes.

Presented in this article are the characteristics of synchronous machines and their use in industry, present teaching methods, the VLSM, the performance evaluation of the virtual laboratory as a simulator and its utility.

SYNCHRONOUS MACHINES AND USE IN INDUSTRY

A rotary electrical machine is a device that has been widely used in industry since the late 19th Century. Electricity has great advantages over alternatives, such as steam, hydraulics and fossil fuels, because of low levels of gas emissions, higher efficiencies and lower cost [4][5].

Synchronous machines are named as such, because the characteristics of them include the relationship between electric frequency (60 Hz in Colombia) and frequency of rotation (consequently, the speed of the motor remains constant). They can be used as generators (feeding them with mechanical energy) or as motors [6-9].

In the technical literature of synchronous machines, emphasis is placed on the special characteristics of these motors (especially in comparison with induction motors), indicating that synchronous motors can deliver between 150 kW and 15 MW, rotating at speeds between 150 rpm to 1,800 rpm [6-9].

They are ideal for use in heavy industry, because induction motors are expensive and inefficient at speeds below 600 rpm, and have a low power factor (the ratio of power available for doing useful work). The power factor of a standard synchronous motor is 1.0, and the ratio between weight and cost is lower than that of an induction motor with the same power and speed characteristics. There are synchronous motors that can work with a power factor of 0.8 advanced to full load, but they are more expensive than those that work with a unit power factor since the excitation and stator currents are higher, since their construction must allow for these conditions [7].

Synchronous machines mostly work as generators and are the main source of electricity generation [9]. An improvement of 1% increases the daily income of the generating companies by thousands of dollars a day. The problem with the construction of generators of great dimensions lies in the evacuation of heat generated by the machine [8][9].

CURRENT SYNCHRONOUS MACHINES

A photograph of a synchronous machine is shown in Figure 1. The machine has a terminal that allows changes in the internal connections of the coils. The current class development methodology is shown in Figure 2.

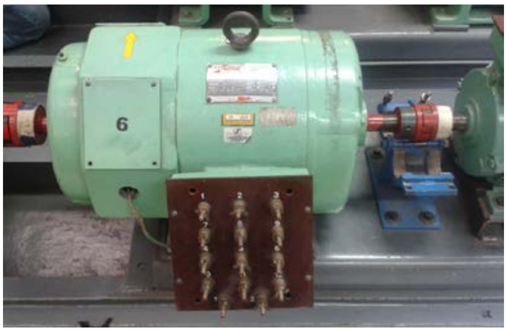

Figure 1: Synchronous machine in the Electrical Machines Laboratory at the National University of Colombia.

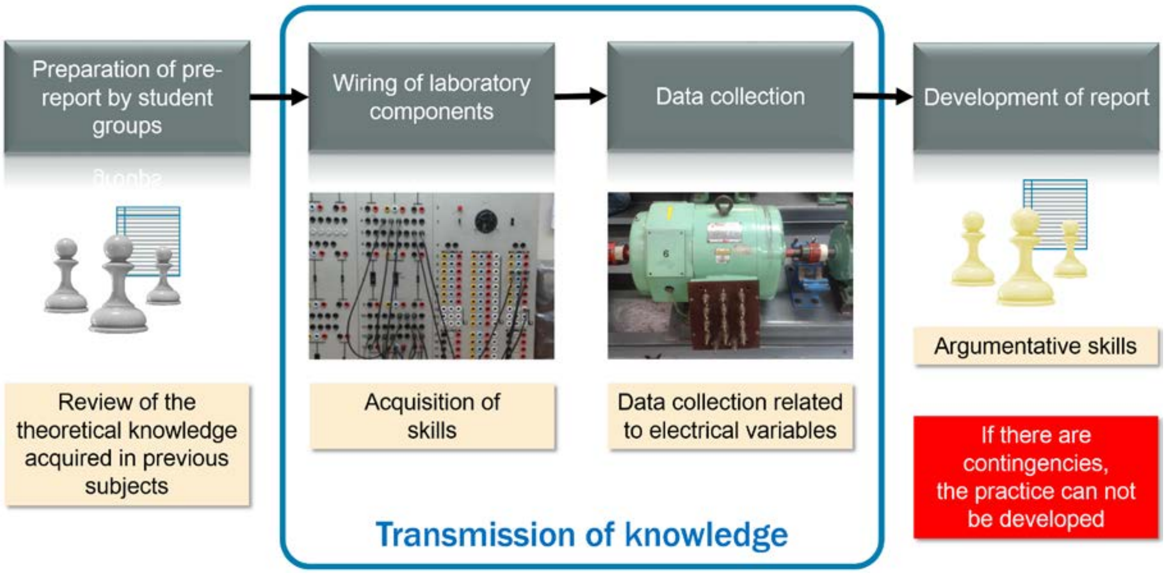

Figure 2: Current class development methodology (Source: Authors).

At present, the study of the synchronous machine is carried out in the Electrical Machines Laboratory of the National University of Colombia. The first step consists of the preparation of a pre-report, where students describe the most important theoretical aspects, i.e. elaborate on the connection diagram of the synchronous machine and the feeding and protection devices.

In the Electrical Machines Laboratory the students perform the wiring supervised by an instructor. The data are collected using the available measuring instruments (i.e. power clamps and network analysers).

The first step in the Electrical Machines Laboratory is the wiring of the protection board. In the Electrical Machines Laboratory, this device, which measures more than four metres by two metres (Figure 3), includes switches, meters and connection points that allow for the connection of power supplies (direct current and/or alternating current), with protections for other points inside the laboratory. This eliminates the need to run a cable from the board to other connection points, which could be most cumbersome.

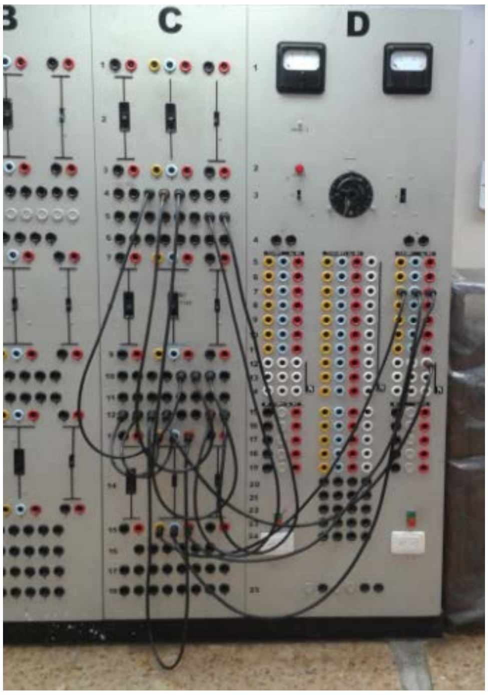

Figure 3: Protection board in the Electrical Machines Laboratory (Source: Authors).

The interconnection points from the protection panel to the different areas of the laboratory is a design element that facilitates the wiring. If this feature is not included, the connections made from the dashboard must have long cables (between three and five metres), which may be damaged due to wear, endangering the physical integrity of them.

THE VIRTUAL LABORATORY AS AN ACADEMIC OPTIMISATION TOOL

The development of the Virtual Laboratory of Synchronous Machines (VLSM) in the Electrical Machines Laboratory allows the user to:

- Familiarise themselves with the power connections from the protection panel. The protection panel is a power supply device that has terminals and protections for the required connections.
- Carry out the necessary wiring to operate the synchronous machine. The simulator allows the user to become familiar with the physical characteristics of the real device.
- Simulate the data obtained from the real device, i.e. the simulation allows the user to practise obtaining data from a real synchronous machine.

Summarised in Figure 4 is the development process of the virtual laboratory. At the start is the analysis of present practice with the synchronous machine. Then, the characteristics of the simulator and the scope of it are determined. Next, the software with the desired characteristics is developed and enabled for use, and the strengths and weaknesses are determined.

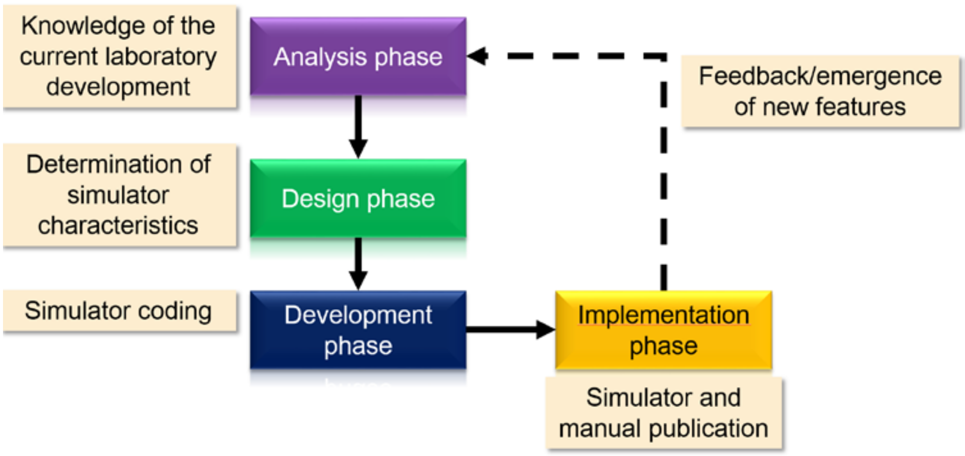

Figure 4: Life cycle of the Virtual Laboratory of Synchronous Machines (Source: Authors).

It is important to highlight the use of 3D graphics in the simulator, because this allows users to obtain a close look of what they will find in a real laboratory (see Figure 5). Circuit diagrams are designed to describe the interconnection between the components of an electrical system, but they lack the physical characteristics of real devices (so much so that the same symbol can be used to represent machines that are different from each other).

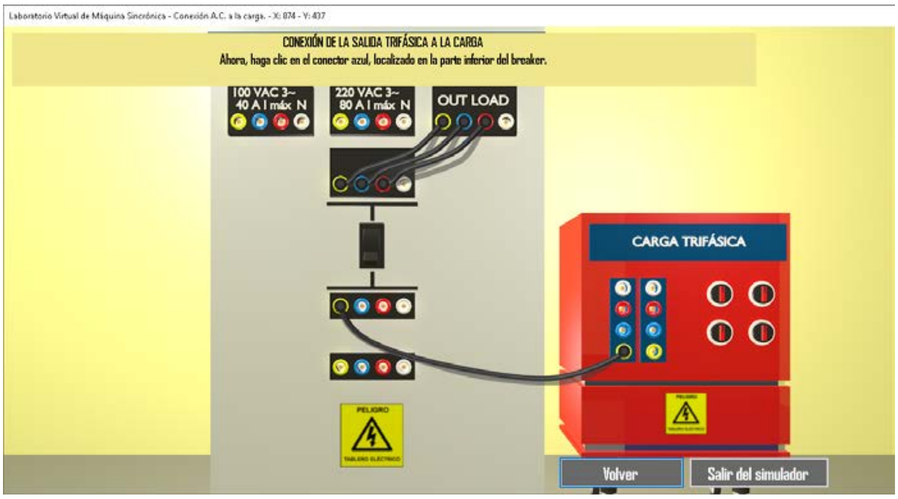

Figure 5: Main menu of the Virtual Laboratory of Synchronous Machines (Source: Authors).

The simulator mimics real laboratory practice. The guidelines for laboratory practices suggest that students should prepare the circuit diagram indicating the connections that will be made, which makes the simulator an instrument that can be used to simulate the connections.

The simulator has modules to find the connections to power the board and connect the load. It simulates a reduced version of the real protection board, i.e. it has several connections for the same type of output. In Figure 5, it can be noted that the number of connections and the distribution of the terminals and switches are different; this gives the user the experience of being in front of a real protection board, which is fundamental to understanding the real laboratory.

The wiring does not necessarily need to follow a specific order, but a sequence is offered, so that the user can execute it both in the simulator and in actual practice. In Figure 6, the original main menu is shown with all the options activated (in Spanish).

Figure 6: Main menu of the Virtual Laboratory of Synchronous Machines (Source: Authors).

The data collection for a real machine has two components: the first consists of adjusting the field current of the synchronous machine with a rheostat, taking note of the induced voltage. The second part consists of evaluating the efficiency of the synchronous machine before any changes in the loads that are fed by it.

In the simulator, the user adjusts the input signals to obtain measurements through virtual instruments that will generate data, which emulates the collection of data in a real environment. Students create a report that includes the data obtained and their technical interpretation. In Figure 7, the screen of one of the modules shows an example of the collected data.

Figure 7: Screen of the efficiency test module against the connected load of the Virtual Laboratory of Synchronous Machines (Source: Authors).

SIMULATOR PERFORMANCE EVALUATION AND SIMULATOR UTILITY

The evaluation of the simulator determined how it could be used in a university. In the Delphi method (a communication technique), students and teachers are evaluated, so as to facilitate planning and decision making. The facilitator of a group organises the information that is received. The advantage of this method is that data collection can be done via e-mail, which is appropriate for a project involving a computer simulator [10].

López explains that there are standardised processes for the evaluation of didactic models (such as those that exist in the royal decrees in Spain), but also indicates that this process must be carried out according to the needs of students and teachers [11].

One of the impacts of the virtual laboratory is described by Capacho as *just-in-time learning:* a teaching culture; the demand for education is so high, it results in students receiving classes from their homes [12]. The VLSM virtual experience can be used as a substitute for real experiences (for example, to obviate individual contingencies as incapacities or collective contingencies such as a strike).

Virtual practice allows students to gain confidence practising their skills in wiring and collecting data. In the future, classes would be set according to the example in Figure 8, including development of the laboratory simulation prior to development of the real counterpart of it. All students will deploy the simulator and develop a report with the data generated by the simulator.

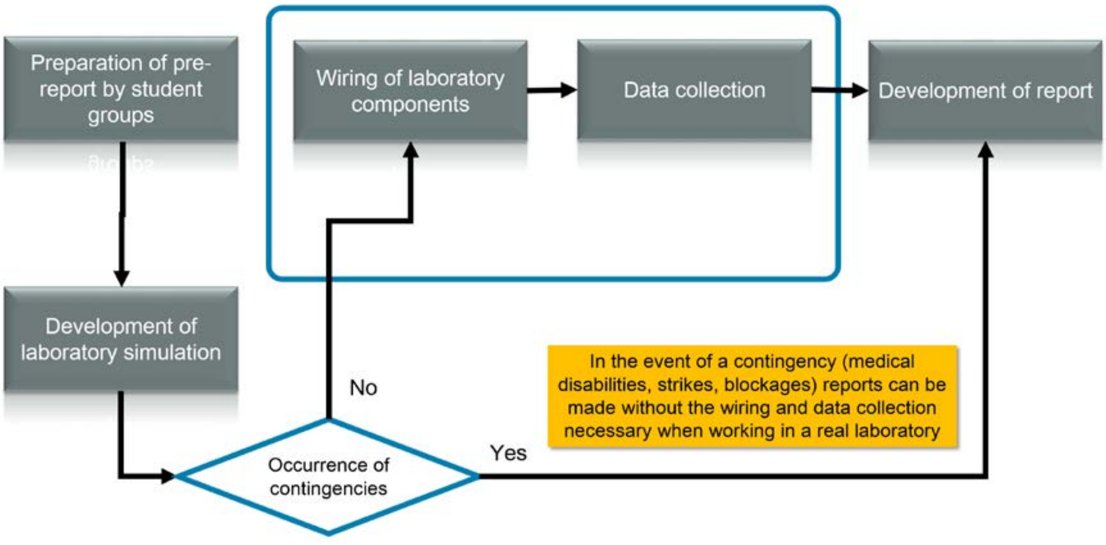

Figure 8: Development of classes with the Virtual Laboratory of Synchronous Machines (Source: Authors).

The methodology for evaluating the virtual laboratory is described in Figure 9. The students are divided into two groups, one of which will continue taking the classes in a traditional way (without using the simulator); the second group will deploy the simulator. The two groups will carry out the wiring and the data collection with instructor supervision. The length of time it takes the groups to complete the wiring, any errors, the quality of the data collected, and their interpretation will all be recorded.

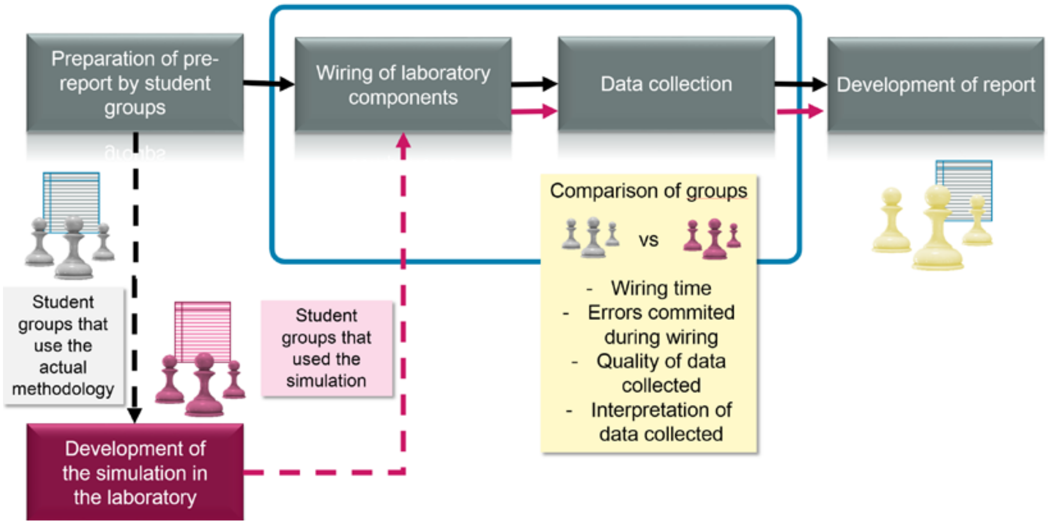

Figure 9: Methodology for evaluating the performance of the Virtual Laboratory of Synchronous Machines (Source: Authors).

Previous virtual practices can prepare the students. As a result, they will gain confidence in developing their skills, resulting in improved learning times, wiring and data collection. Students can recreate actual laboratory practice from their computers.

The gap between industry and academia becomes smaller as virtual environments are developed at university laboratories, because the academic approach to industry applying virtual environments should allow students to acquire skills that allow them to perform tasks efficiently in industry.

Students' integration into industry requires the reinforcement of their knowledge in the area related to the job and the position that they acquire. It is normally not practical for students to recreate actual practice during undergraduate studies. The virtual laboratory makes this much simpler.

CONCLUSIONS

A simulator often conveniently uses a reduced version of the real instrumentation of the simulated system. The imitation of a device must be reduced to the functional minimum, which is reached with the least possible number of simulated elements.

The application of simulators in an academic setting allows users to overcome individual or collective obstacles in classes. Depending on the context in which contingencies occur, the decision to deploy the simulator would fall on teachers and/or students. Therefore, a virtual laboratory should not be used nor should it be seen as a social instrument by which to disrupt social protest movements.

In the development of classes in the Electrical Machines Laboratory of the National University of Colombia in Bogotá, the Virtual Laboratory of Synchronous Machines may be evaluated alongside virtual laboratories of single phase transformers and induction machines. In this way, a more uniform evaluation of the performance of ICT in the classroom can be made.

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BIOGRAPHIES

John Ramirez holds a BSc in electrical engineering from the National University of Colombia (2016). He developed technical studies in systems and computing from the Pilot Industrial Technical Institute. He has worked in the development and programming of virtual laboratories of single phase transformers (2016), induction machines (2017) and tension tests with steel rods (2017) at Universidad Nacional de Colombia.

Diego Rodríguez-Medina holds a BSc in electrical engineering from the National University of Colombia (2012). He also holds an MSc in electrical and computer science engineering from the University of Oklahoma (2014). At present, he is a PhD student in the Department of Electrical Engineering at the National University of Colombia. Additionally, he is the international studies manager at Consulting Engineers (GERS), Weston, Florida, the United States of America.

Sergio Rivera Rodríguez holds a BSc in electrical engineering from the National University of Colombia (2001). He also holds a PhD in engineering from the National University of San Juan. He was an associate postdoctoral fellow at the Massachusetts Institute of Technology (MIT), Boston, USA (2013), and a postdoctoral fellow at the Masdar Institute of Science and Technology (MIST) in Masdar City, Abu Dhabi, United Arab Emirates (2014). At present, he is a Professor at the National University of Colombia in the area of power systems and electrical machines.