

A Simulation-Assisted Teaching Practice: Teaching AC Variable Speed Systems Using Simulation Models Library

Yang Qian^{1,*}, Gao Jinzhu²

¹School of Mechanical and Electrical Engineering, Xi'an University of Architecture and Technology, Xi'an, China

²Department of Computer Science, University of the Pacific, Stockton, USA

Email address:

yangqian0516@126.com (Yang Qian), jgao@PACIFIC.EDU (Gao Jinzhu)

*Corresponding author

To cite this article:

Yang Qian, Gao Jinzhu. A Simulation-Assisted Teaching Practice: Teaching AC Variable Speed Systems Using Simulation Models Library. *Science Journal of Education*. Vol. 9, No. 3, 2021, pp. 87-95. doi: 10.11648/j.sjedu.20210903.13

Received: April 28, 2021; **Accepted:** May 19, 2021; **Published:** May 24, 2021

Abstract: Different modulation modes of PWM technology and inverters can be selected for different types of the motors, a variety of AC variable frequency variable speed system structures can also be derived based on the same control principle. So it brings a great challenge to teaching AC variable speed systems. We have identified four factors that hinder students' learning in this topic: 1) the abstraction of the mathematical logic behind the control theory; 2) the complexity of system structures; 3) the diversity of implementation methods; 4) lack of motivation to explore more engineering applications due to boring textbook contents. To facilitate and inspire student learning, we developed an innovative way to teach the AC Variable Speed Systems course using the simulation models library. The library was implemented based on MATLAB/Simulink to assist students in studying five different types of AC variable speed systems. We assessed the effectiveness of our new teaching practice by evaluating students' cognitive and affective behavior under both the traditional lecture-based teaching environment and the new simulation-assisted teaching environments. The practice assessment tools that take into accounts the in-class performance (attendance accounts for 10% and the experimental reports account for 20%), the lab assignments computer operation score (30%) includes software operation (10%) and system constitution and design (20%), and the final exam (40%) are designed to assess the students' understanding of AC variable speed systems. The student group learning under the simulation-assisted teaching environment delivered a superior performance in all measures including the noticeable improved scores on the final exam. We also developed a survey to evaluate the students' affective behavior by measuring their motivation for learning and their perceptions of effectiveness of practice. Ninety percent of students reported that the new teaching practice using the simulation models library is much more interesting and inspiring than the traditional lecture-based teaching approach.

Keywords: AC Variable Speed Systems, Simulation-assisted Teaching Methodology, MATLAB/GUI, Simulation Models Library, Vector Control, Practice Training

1. Introduction

The concept of computer simulation, that is a vivid imitation of the structure, function and behavior of the system, was first introduced in 1960s. Since then, different types of simulation software and simulation instruments, such as MATLAB, Pspice, Labview, Finite, and dSPACE, emerged in an endless stream. As simulation software, MATLAB is mainly used for scientific computing, data analysis and visualization, and interactive programming. As

the family member of MATLAB, Simulink is a visual simulation tool, which supports dynamic system modeling and simulation analysis of linear systems, nonlinear systems, digital control and DSP systems. The power system toolbox of Simulink is a module base dedicated to the RLC circuit, power electronic circuit, motor drive control, and power system simulation. It contains a variety of AC / DC power supply and a large number of electrical components, electrical measuring instruments and analysis tools [1, 2]. MATLAB can also be used as a technology assisted tool for teaching electrical engineering theoretical concepts on power

electronics [3], electrical machinery [4], and automatic control principle [5, 6].

Over the years, we have noticed that Electrical Engineering students are more motivated to learn abstract control theoretical concepts when they have chance of doing experiments both in and outside the classroom. This type of learning is called active learning [7, 8]. Nowadays, however, for a large class, teaching through practical experiments can be a challenge due to limited lecture/lab time and teaching funds. One of the solutions is to develop a course simulation models library to support practical experiments in a large classroom setting, a “must” in order to provide cutting edge learning environment for electrical engineering students [9].

There have been many research works on the necessity and effectiveness of various teaching methods [10-13]. More recently, some researchers have also studied simulation-assisted teaching approaches in Electrical Engineering education. Porobic [14] reported on the benefits of using the electrical drive laboratory. Amélie Chevalier and Cosmin Copot [15] studied the effectiveness of a remote laboratory used in teaching control engineering for three years.

At the Xi'an University of Architecture and Technology, about 120 students started their Electrical Engineering education in the 2020–2021 academic years. All the undergraduate students need to take the courses in power electronics, electrical machinery, motor and its drag and automatic control principle. The Schools of Mechanical Electronics, Mechanical Manufacturing & Automation, as well as the Schools of Information & Control Engineering, Civil Engineering and Environmental & Municipal Engineering all offer courses in AC and DC variable speed systems. For example, Automatic Control Principle is the course that teaches students the basic theoretical concepts and analysis methods of automatic control systems. Graduate students in electrical engineering also need to take the AC variable speed systems course that covers advanced control methods, system constitutions and realization methods of AC variable speed systems. For electrical engineering students, real-life experiments can help them gain a better understanding of the control principles [14]. However, students may not be able to do this due to

- 1) increasing enrollment each year;
- 2) limited training funds that are not enough to provide the necessary lab equipments for a large number of students;
- 3) limited lab time to do practice experiments.

Obviously, a functional simulation models library can provide a viable solution to this issue within the existing constraints. Our main goal is to provide a direct and effective teaching and learning platform for undergraduate courses rather than showing a demo as mentioned in [4, 14] or simply implementing and improving the existing control methods as mentioned in [1, 2, 6, 16-20], and then develop more advanced experiments for graduate courses. As the undergraduates by far outnumber the graduate students, basic simulation models library make it possible to give a large number of students an opportunity to practice. The graduate

students can learn more advanced control methods by replacing some modules with the controller subsystems modules of the basic simulation models.

Several project assisted teaching efforts for AC Variable Speed System provide ample examples of interesting motor control solutions, such as direct torque controller [16], variable structure controllers [17], model reference adaptive controller [18], artificial neural networks for speed estimation [19] and fuzzy logic controller for eliminating torque ripples during the starting condition [20].

In order to improve the students' understanding of AC variable speed systems, a simulation models library based on Simulink was developed. The library consists of five distinct applications, namely, the adjustable voltage and adjustable speed system, variable voltage variable frequency (VVVF) speed control system, vector control system, direct torque control system, and cascade speed control system that differs from the current available resources. The five simulation models represent five development directions of AC variable speed systems. The concept of the Simulink subsystem is introduced, and each speed control system model is divided into subsystems according to their functionalities, which philosophy of the simulation models library based on Simulink. Another goal is to investigate the effectiveness of the simulation assisted teaching methodology by observing student behavior change from the cognitive and affective standpoints.

The rest of this paper is structured as follows. First, in Section 2, the structure of simulation assisted teaching methodology using a simulation models library is described. Then, in Section 3, the development of the simulation models library is explained in detail through an example. Finally, in Section 4, the evaluation strategies are discussed, and the evaluation results are shared.

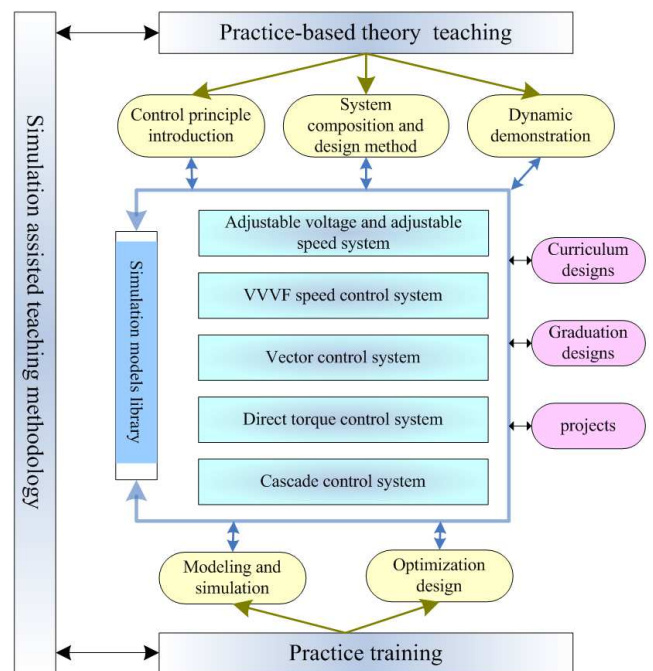


Figure 1. The structure of simulation assisted teaching methodology.

2. The Structure of Simulation Assisted Teaching Methodology

The AC Variable Speed Systems course is a required course for electrical engineering students. It is necessary to develop an effective teaching methodology to help students deepen their understanding of the abstract control theoretical concepts, system constitutions and design method of AC variable speed systems. By using the simulation models library based on Simulink, we developed a simulation assisted teaching methodology for the AC variable speed systems course, as shown in Figure 1. The simulation assisted teaching methodology is implemented in two stages: practice-based theory teaching and practice training.

During the practice-based theory teaching stage, the instructor first explains the basic control concepts in detail so that the students could have a basic understanding of the control principle of AC variable speed systems. After that, the system simulation model is used to further explain the composition of the AC variable speed system, the relationship between different components, and the possible

design methods of AC variable speed systems. The simulation model is demonstrated interactively by the instructor so that students can observe the change of the dynamic performance of the control system under external disturbances and system parameters changing, and eventually understand the impact of control method on the system performance, as shown in Figure 2.

Because of the limitation of students' comprehensive ability and the study time, it is impossible for the undergraduate students to fully understand the knowledge points and finish the system modeling and simulation in a short time. During the practice training stage, students are required to set up their own AC variable speed systems models guided by the given simulation demos. In this way, they can get a clear understanding of every part in an AC variable speed system. After that, for a given AC variable speed system, the instructor explains the plan for optimization, then the students finish the plan and evaluate effectiveness of the given method. Throughout the process, whenever there is a new problem, the instructor would lead a discussion and work together with students to identify potential solutions.

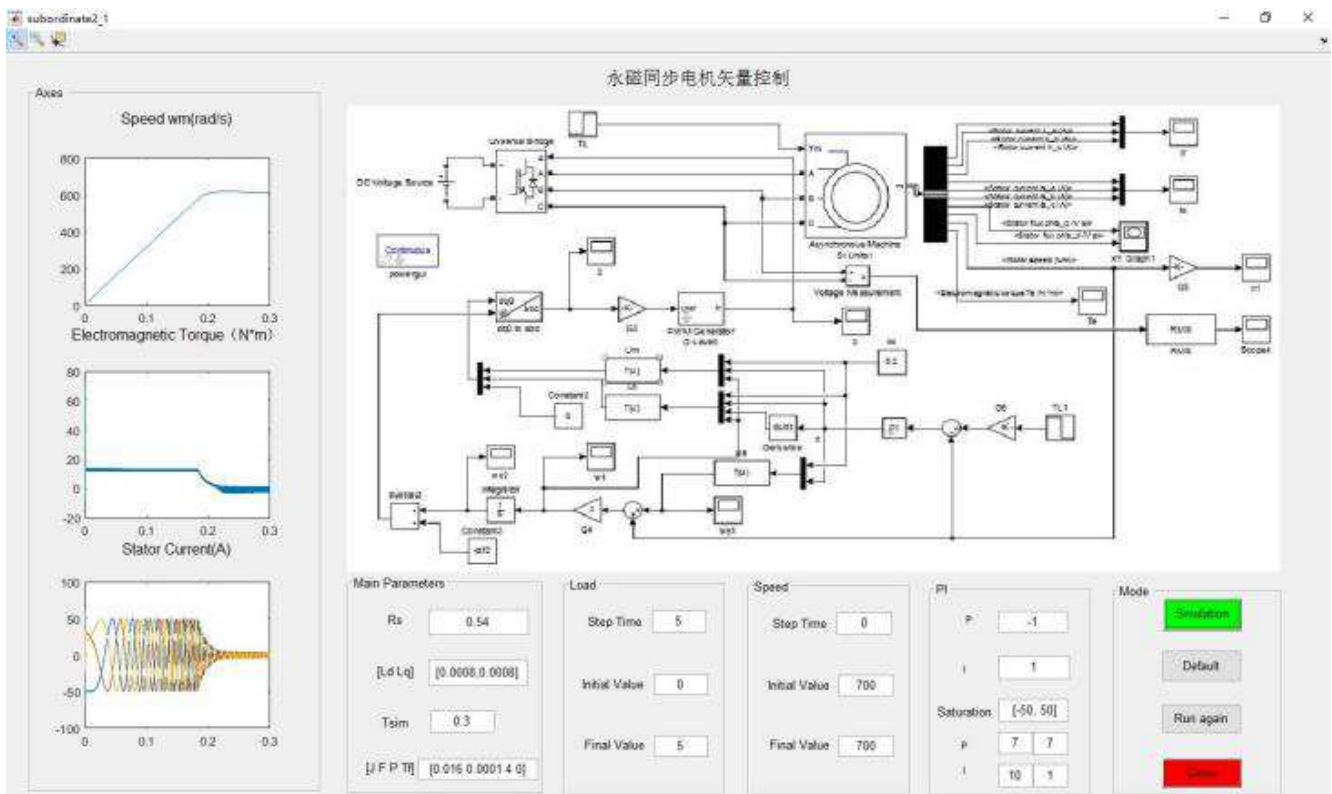


Figure 2. The demonstration interface of AC variable speed systems based on MATLAB/GUI.

3. Design of Simulation Models Library

Through the simulation models library, students are able to access specific applications of AC variable speed system in the university lab. The simulation models library presented here allows a diverse group of students to study the control methods of AC variable speed system such as cascade speed control system or other advanced control techniques (e.g.,

space vector control model, direct torque control model, etc.). The advantage of the simulation models library is its local replaceability.

A set of typical application examples of AC variable speed systems was selected as the simulation models. As mentioned in Section 1, our simulation models library based on Simulink consists of five different applications. In fact, the simulation examples of the AC variable speed systems in

curriculum designs, graduation designs and projects can also be used as typical application cases to enrich the simulation models library.

Because of introducing the concept of Simulink subsystem, hierarchical simulation demos were built with dividing each AC variable speed system model into subsystems according to functions. Guided by the demos, the students first build their own AC variable speed system simulation model to learn the basic control concepts, system constitutions and design methods. Then, they optimize the system by replacing the corresponding function subsystems, which greatly reduces the modeling time and improves the efficiency of the practice training.

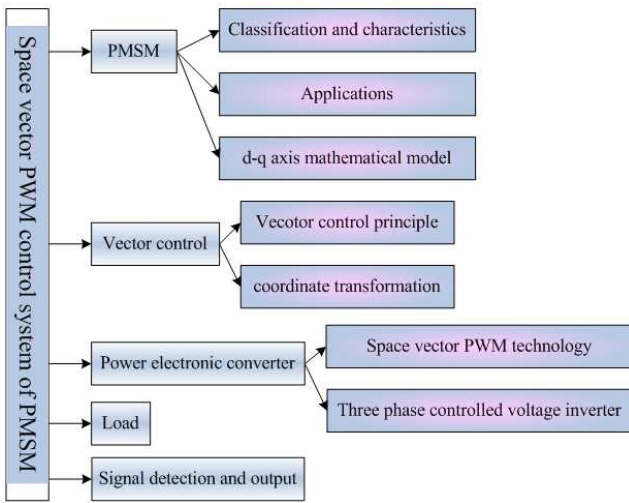


Figure 3. The knowledge points covers in the SVPWM control system of PMSM.

Here we use the space vector control (SVPWM) system of permanent magnet synchronous motor (PMSM) as an example to explain the design method of creating a hierarchical simulation model. The knowledge points covered in the SVPWM control system are shown in Figure 3.

With the advantages of no excitation current, high efficiency, high power factor and high power density, the permanent magnet synchronous motor AC variable speed system has an excellent low speed performance, and allows high speed control of weak magnetic field. Because of its wider speed regulation range, PMSM can easily meet the requirements of high-performance driving technology. The SVPWM technology is the sine PWM technology from the angle of the motor. Considering the inverter and the motor as a whole, the SVPWM technology focuses on how to make the AC motor produce a constant rotating circular magnetic field. As its simpler system structure, easier and higher voltage utilization, the SVPWM technology has been widely used in AC variable speed systems.

The key knowledge points of PMSM space vector control technology include 1) the rotor d-q axis mathematical model of PMSM; 2) the vector control principle and coordinate transformation; 3) the SVPWM technology and 4) the three-phase controlled voltage inverter. In addition, it is essential to develop an equivalent load model according to the external disturbance characteristics. In order to achieve the signal transmission and observation, it is a “must” to include the signal detection and output modules. In fact, the actual SVPWM control system of PMSM includes 6 subsystems. The space vector PWM control system’s simulation model of PMSM is shown in Figure 4.

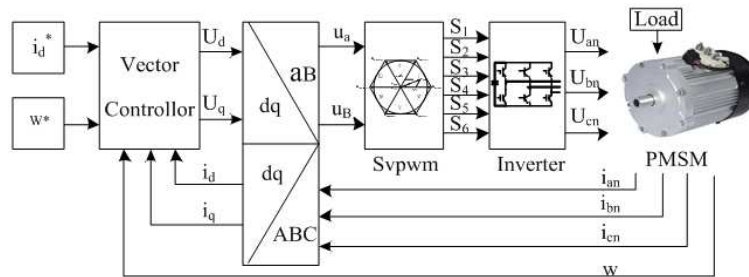


Figure 4. The space vector PWM simulation model of PMSM.

The major challenge is the subsystem modeling of SVPWM modulation method, as shown in Figure 5.

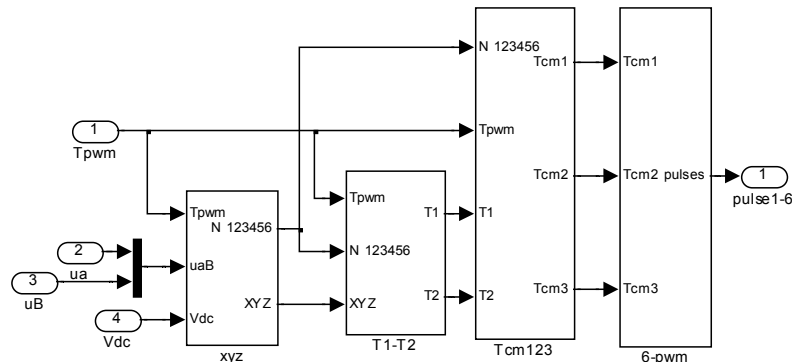


Figure 5. The Space vector PWM subsystem simulation model.

First, according to the given stator axis voltage, the current sector is judged. Then, the action voltages expressed by XYZ and the action time T_1 and T_2 are calculated respectively. After that, the switching points T_{cm1} , T_{cm2} and T_{cm3} of the sine PWM waveform are deduced from the action time T_1 and T_2 . Finally, the six switch control signals of the voltage inverter are obtained.

4. Evaluation

The goal of our evaluation plan was to measure the changes in students' cognitive and affective behavior. Measuring the changes in students' cognitive behavior is aligned with the project's first objective of improving students' understanding of the control principle of AC variable speed systems. Measuring the changes in students' affective behavior is aligned with the project's second objective of motivating students to learn AC variable speed systems.

4.1. Comparison of Two Teaching Methodology

Before presenting results, we would like to explain the differences between the traditional teaching methodology and simulation assisted teaching methodology.

Traditional teaching methodology: Nowadays, the traditional form of specialty teaching can be achieved by the use of new media, which effectively increases instructor's productivity and improves the students' learning environment. When the instructor lectures, the students passively receive information. The biggest highlight in a lecture is the interactive demonstration of instructor research achievements, which may attract students instantaneous attention and enthusiasm. However, the teaching effectiveness is still very limited, and it is impossible to give each student individual attention.

Simulation assisted teaching methodology: According complexity of a topic to be covered, an instructor can adaptively allocate lecture and practice hours. With the help of interactive new media contents, the instructor explains the basic control concept and demonstrates the system simulation model. Students can easily observe the impact of control

method on the dynamic performance of an AC variable speed system. Under the guidance of the instructor, students play an active role in learning system modeling, dynamic simulation and performance analysis of AC variable speed systems under external disturbances. After the instructor releases the optimization plan, the students work in groups to finish the plan by replacing the function subsystems. In this way, students get a deeper understanding of the control principle and system composition of AC variable speed systems.

The traditional evaluation method of usual performance (30%) plus final exam scores (70%) is adopted in specialized courses assessment. The disadvantages of this assessment method include: 1) If students attend the class and finish the homework correctly, they can get 30% of the usual performance regardless of whether they listen or not to the lecture and whether the homework is finished independently or plagiarized; 2) As long as students' final exam scores are 43 points or more, they can pass this course, which doesn't truly reflect the students' understanding of the course. In 2017-2018 academic years, due to the traditional teaching method, the traditional evaluation method is used to assess the teaching effectiveness of AC Variable Speed Systems. In 2018-2019 academic year, because simulation-assisted teaching method is used, the practice evaluation method of integrating usual performance score (30%), computer operation score (30%), and final exam score (40%) is adopted in AC variable speed systems course assessment. The attendance rate only accounts for 10% and the experimental reports account for 20% in the usual performance; the computer operation score reflects the students' cognition of the AC variable speed system composition and implementation methods; and the final exam score reflects the understanding of professional knowledge points. The practice evaluation method can objectively evaluate students' understanding of the course. The results from both traditional teaching methods and simulation-assisted teaching methods are shown in Table 1. Distribution of the scores in traditional teaching method is shown in Figure 6 and distribution of scores in simulation-assisted teaching methods is shown in Figure 7.

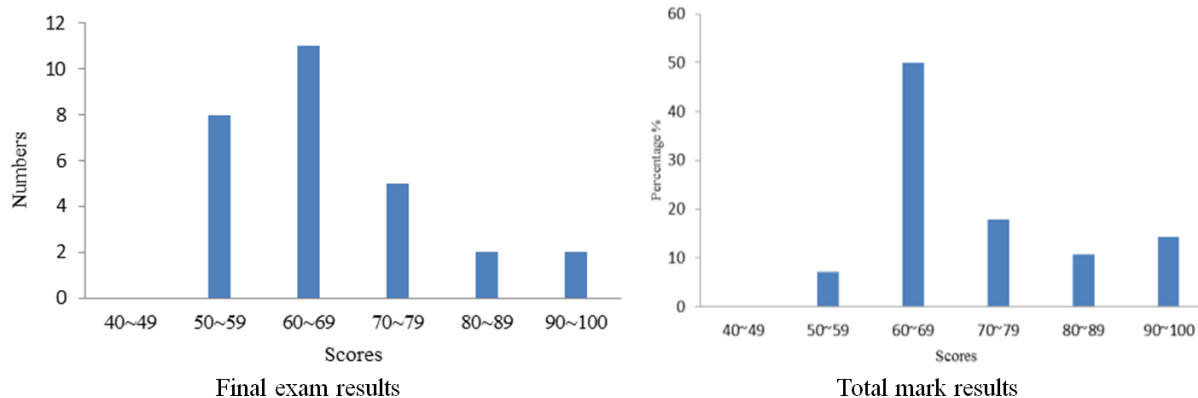


Figure 6. Traditional teaching methodology.

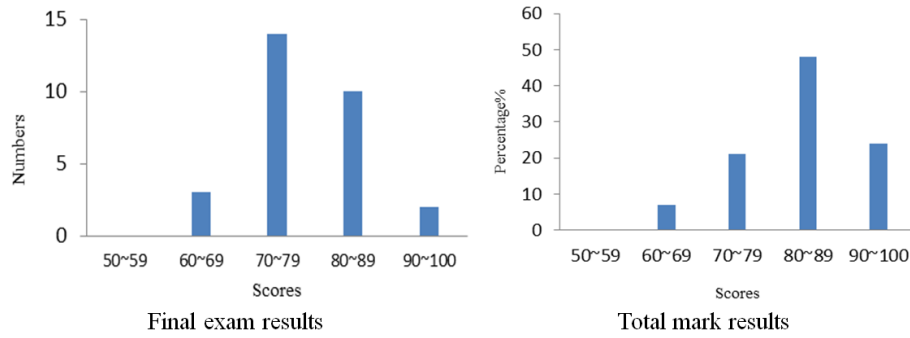


Figure 7. Simulation-assisted teaching methodology.

Table 1. The survey results from two teaching methodology.

Teaching methodology	Final exam results			Total mark results			
	Average value	Pass rate	Standard deviation	Average value	Pass rate	Standard deviation	Highest scores
Traditional	60.1	71.4%	5.6	71.5	92.9%	12.1	96
Simulation assisted	79	100%	7.3	83.3	100%	6.7	97

Students evaluated the instructor (Yang) from 10 aspects, as shown in Table 2.

Table 2. Annotation table for instructor.

	Evaluation	Evaluation Items	Scores	Final scores
1	Attitude	Focus on the education of students' moral and values	10	
2		Full-spirited, dignified, not taking a sitting position to teach	10	
3		The concept is accurate and highlight the difficult points	10	
4	Content	Well prepared and well organized	10	
5		Reasonable teaching contents, and emphasize the linking with theory and practice	10	
6	Methods	Focus on class discussion and case teaching	10	
7		Neat blackboard writing, high level lecture PPT	10	
8	Effectiveness	Active class atmosphere and orderly class order	10	
9		Focus on the cultivation of students' innovative ability, and give them exploring space	10	
10		Well interact	10	

The instructor (Yang) relied on the rubrics used in AC variable speed systems to evaluate whether a student meets learning requirements (or at least at the Practitioner level), as shown in Table 3. By analyzing the results, we realized that the simulation assisted teaching methodology is more effective in keeping students engaged as it allows the students to learn actively under the instructor guidance. And

the instructor is able to build a productive relationship with students. In addition, the enthusiasm and creativity of the students can be maximally stimulated throughout the practice process. From our experiences, for professional courses, more teacher-student interaction is desirable since it gives students more guided practices.

Table 3. Evaluation form of students' practical ability.

Item	Novice	Practitioner	Expert
Adjustable voltage and adjustable speed system	Cannot design an appropriate adjustable voltage and adjustable speed system for a simple project.	Understands how to build an adjustable voltage and adjustable speed system and can usually identify the best choice for a particular project.	Understands the different adjustable voltage and adjustable speed system structures and design methods, and always uses the best choice for a particular project.
VVVF speed control system	Cannot design an appropriate VVVF system for a simple project.	Understands how to build VVVF systems and can usually identify the best choice for a particular project.	Understands the different VVVF system structures and design methods, and always uses the best choice for a particular project.
VC system	Cannot build an appropriate VC system for a simple project.	Understands how to design a VC system model and can usually identify the best choice for a particular project.	Understands the different VC system structures & optimization methods, and always uses the best choice for a particular project.
DTC system	Cannot setup a DTC system for a simple project.	Understands how to build DTC system and can usually identify the best choice for a particular project.	Understand the DTC structures & optimization methods and can build DTC system for a particular project.
Cascade speed control system	Cannot build a cascade speed control system for a simple project.	Understands how to establish cascade speed control system model.	Understands the cascade speed control principle, system constitutions and design method, and can design cascade speed control system for a particular project.

The following are some feedbacks on the method of simulation assisted teaching methodology from a wide variety of students.

“It is the first time I can build my own control system model by myself.”

“The interviewer was so impressed that I used MATLAB/Simulink in my space vector controller design.”

“I really learned a lot of useful control methods. In fact, I talked about direct torque control method we learned in class during my interview with XD, and I think that actually helped me get the job.”

“The instructor taught us how to study AC variable speed systems without giving the answers directly. She was willing to give helpful suggestions when we have issues.”

“The instructor created a positive learning environment and made learning more interesting. She provided useful demos and suggestions that stimulated our learning interests. For example, the variable voltage variable frequency speed control system lab was very helpful in establishing the AC variable speed system framework. The optimization questions asked are also helpful, which kept the class engaged.”

4.2. Other Results

In addition to the qualitative results, we also gathered critical pedagogical information for improving our future teaching plan. These include more reasonable lectures and practice planning, more efficient system models, improved optimization questions, appropriate cross integration of other disciplines in the course, gathering student feedback and subsequently providing real-time remediation opportunities, as well as other intangible outcomes which influenced both the instructors and student affective domain, namely life target, and interests & hobbies and emotions towards teaching and learning.

Specifically, the data we have collected include:

Lesson and practice plans were prepared in an intentional manner prior to the class;

Lessons of AC variable speed system include theoretical concepts, mathematical model, steady-state analysis and implement method;

Practice integrating students' learning outcomes (what we wish the learners to know or be able to do and under what conditions are measurable);

Attitude;

Operation, methods and papers associated with control method;

Equations, tables and conclusions, as well as cited resources.

At the end of semester, we ask students for their opinions on the lectures, the simulation models and the teaching pace. We also ask for their suggestions. Students' feedbacks have been very useful for us to make adjustments to teaching and practice plans, especially when we need to teach the same course again in the near future. When we prepare lessons for the first time, we would request similar information from previous

instructors and students. Formative assessment: To check students learning outcomes, we observe students as they ask or answer questions in class. When using simulation assisted teaching, we observe the whole process from students building simulation models to fully understanding materials. The student reaction from different levels is also used so that instructors can adjust the pedagogical pace to meet students needs. Based on our observations, we used a rubric, such as the one shown in Table 3, which contained specific criteria as to the type of critical behaviours and outcomes.

Integration of technology: Frequently, we utilized instructional technology to improve the communication between the instructor and the students. For example, we created a Forum area on WeChat to allow both the instructor and the students to share their resources, questions and suggestions on the course. The instructors answered the questions whenever they were free. We kept a record of the comments and suggestions which would help the instructors make necessary adjustments.

Real-time remediation opportunities: During lecturing, we teach the AC variable speed system control principle, system structure and implementation method. During lab, the students are expected to set up the simulation models by themselves to demonstrate that they fully understand the whole control algorithm, system constitution and design method. We then checked on each student report and, whenever possible, gave them hints and encouraged them to make corrections or improvements. We use this approach in most of our Electrical Engineering courses and found that it speeds up students learning process and greatly improves students learning efficiency.

Affective domain: The affective domain typically includes factors such as student motivation, attitudes and interests. In order to enhance active learning, the instructor should consider the affective domain when planning courses, delivering lectures, developing practice excises, and assessing student learning outcomes. We achieve this by talking to students who took the same course in previous years and, before or after each class, frequently checking on students' feeling through relaxed conversation. For example, when working on the first simulation experiment, many students were not so familiar with the MATLAB/Simulink and cannot find the specific elements. To help them out, the instructor wrote a manual with detailed practice guidance. Students can just follow the manual step by step to get familiar with the component library of the power system toolbox. Whenever the students ran the simulation model and got the correct waveforms, we could see their happy smiles and immediately noticed their learning interests are greatly increased.

5. Conclusion and Future Work

5.1. Conclusion

We have studied a simulation assisted teaching

methodology based on simulation models library to help students actively learn AC Variable Speed Systems. When we developed the simulation models library, the concept of Simulink subsystem was introduced, and each AC variable speed system model was divided into subsystems according to functions, which creates a hierarchy simulation models. Our simulation models are used to assist both lecture and practice. The practice-based theory teaching addresses our first objective to enhance students' understanding of the control principle, system constitutions and design method of AC variable speed systems as well as to broaden students' horizons. The practice training addresses our second objective to increase their motivation for active learning, improve hands-on ability and career opportunities. The survey results demonstrate that we can improve teaching effectiveness and students' interests in learning AC variable speed systems through simulation assisted teaching methodology. Students become more involved in practice process and their creativity was also increased through different practice trainings.

5.2. What We Plan to Do Next

We have discovered the potential of using simulation assisted teaching methodology and the benefits of adopting the student-center approach. In the future, we will implement this method in other classes, enrich the simulation models library, develop more advanced experiments at graduate level, and practice other teaching tools, such as MOOCs and micro-classes. In this paper, we limit our discussion to AC variable speed systems course education. However, for most electrical engineering courses including motor and its drag and motion control, this simulation assisted teaching methodology can also be useful. To demonstrate this, we will coordinate with instructors of other courses and establish an integrated simulation models library that supports multiple courses and multiple instructors.

References

- [1] Patel Hetal, Chandwani Hina, "Simulation and experimental verification of modified sinusoidal pulse width modulation technique for torque ripple attenuation in Brushless DC motor drive," *Engineering Science and Technology- An International Journal-Jestechiee*, vol. 24, no. 3, pp. 671-681, Jun. 2021.
- [2] P. Ahhisek, D. Sukanta, al, A; Das, S; C. Ajit K, "An Improved Rotor Flux Space Vector Based MRAS for Field-Oriented Control of Induction Motor Drives," *IEEE Trans: Power Electronics*, vol. 33, no. 6, pp. 5131-5141, Jun. 2018.
- [3] K. Nayan, S. T. Kumar, D. Jayati, N. Saha, TK, D. Jayati, "Control, implementation, and analysis of a dual two-level photovoltaic inverter based on modified proportional-resonant controller," *IET Renewable Power Generation*, vol. 12, no. 5, pp. 598-604, Apr. 2018.
- [4] B. Amar, D. Hind, and B. Hocine, "Computer-Aided Teaching Using MATLAB/Simulink for Enhancing an IM Course With Laboratory Tests," *IEEE Trans: Education*, vol. 54, no. 3, pp. 479-491, Aug. 2011.
- [5] Sabanin, V. R., Starostin, A. A., Repin, A. I., Popov, A. I., "Study of Connected System of Automatic Control of Load and Operation Efficiency of a Steam Boiler with Extremal Controller on a Simulation Model," *Thermal Engineering*, no. 2, pp. 82-92, 2017.
- [6] Hu Yunfeng, Gu Wanli, Liang Yu, Du Le, Yu Shuyou, and Chen Hong, "Start-stop control of hybrid vehicle based on nonlinear method," *Journal of Jilin University*, vol. 47, no. 4, pp. 1207-1216, 2017.
- [7] M. Alejandra J., V. Camilo, B. Mireille, "Characterizing Engineering Learners' Preferences for Active and Passive Learning Methods," *IEEE Trans: Education*, vol. 60, no. 1, pp. 46-54, Feb. 2018.
- [8] S. L. Oriel, H. Romeu, and B. E. Augustoeman, "On the students' perceptions of the knowledge formation when submitted to a Project-Based Learning environment using web applications," *Computers & Education*, vol. 117, pp. 16-30, Feb. 2018.
- [9] O. Leary, Shattuck, J. S. Julie, and K. Joel, "Interactive Renewable Energy Laboratory," *IEEE Trans: Education*, vol. 55, no. 4, pp. 559-565, Nov. 2012.
- [10] Zhang zhe, H. C. Thorp, and A. Michael A. E, "Teaching Power Electronics With a Design-Oriented, Project-Based Learning Method at the Technical University of Denmark," *IEEE Trans: Education*, vol. 59, no. 1, pp. 32-38, Feb. 2016.
- [11] Liu Huijuan, Zhang Zhenyang, Song Tengfei, "Case study of enquiry-based learning designed for rotating magnetic fields in electric machinery course," *International Journal of Electrical Engineering Education*, vol. 54, no. 4, pp. 341-353, Oct. 2017.
- [12] M. Davis, H. Miguel E, and R. Gustavo A., "A Realistic Generator of Power Quality Disturbances for Practicing in Courses of Electrical Engineering," *Computer Applications in Engineering Education*, vol. 23, no. 3, pp. 391-402, May. 2015.
- [13] Pozo-Ruz A, Duran M. J., Sanchez-Pacheco F. J., Rivas-Montoya E, Sotorrio-Ruiz P. J., and Trujillo-Aguilera F. D., "Multidisciplinary Power Electronics Courses with On-line Simulation Tools," *International Journal of engineering Education*, vol. 32, no. 2, pp. 948-955, 2010.
- [14] Ji Xuande, "Application of MATLAB Software in Motion Control System's Teaching," *Proceedings of the CSU-EPSA*, vol. 22, no. 3, pp. 156-160, Jun. 2010.
- [15] C. Amelie, C. Cosmin, and I. Clara, "A Three-Year Feedback Study of a Remote Laboratory Used in Control Engineering Studies," *IEEE Trans: Education*, vol. 60, no. 2, pp. 127-133, May 2017.
- [16] M. Murli, and D. Sukanta, Current Sensor Fault-Tolerant Control for Direct Torque Control of Induction Motor Drive Using Flux-Linkage Observer, *IEEE Trans: Industrial Informatics*, vol. 13, no. 6, pp. 2824-2833, Dec. 2017.
- [17] Z. Mohamed, T. Ezzeddine, A. Haitham, "Two-Degrees of Freedom and Variable Structure Controllers for Induction Motor Drives," *Advances in Electrical and Computer Engineering*, vol. 18, no. 1, pp. 71-80, 2018.

- [18] P. Ahhisek, D. Sukanta, and C. Ajit K., "An Improved Rotor Flux Space Vector Based MRAS for Field-Oriented Control of Induction Motor Drives," *IEEE Trans: Power Electronics*, vol. 33, no. 6, pp. 5131-5141, Jun. 2018.
- [19] B. Pavel, and K. Martin, "Sensorless control of variable speed induction motor drive using RBF neural network," *Journal of Applied Logic*, vol. 24, special. SI, pp. 97-108, Nov 2017.
- [20] J. Jino, and Ushakumari S., "Performance comparison of a Canonical Switching Cell with SPWM and SVPWM fed sensorless PMBLDC motor drive under conventional and fuzzy logic controllers," *Journal of the Franklin Institute-Engineering and Applied Mathematics*, vol. 354, no. 14, pp. 5996-6032, Sep. 2017.