A Case Study about Innovative Electromagnetic Engineering Education based on Capacitor Charging and Discharging

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Abstract:—Capacitor charging and discharging is basic knowledge in electromagnetic education. This work proposes an innovative course teaching method of “self-learning as the mainstay, supplemented by circuit examples”, which can improve the student’s knowledge absorption and enthusiasm in the class. The simulation tool Multisim is used as an auxiliary software to strengthen the connection between theory and practice, which reviews the knowledge they have learned and helps students to develop the habit of using simulation software to assist their learning. This innovative course teaching method improves the role of students in the classroom and cultivates the ability of students to learn independently and practice automatically, lays a foundation for the design of electromagnetic theories in the future.

Keywords: Circuits Theory, Circuits Experiment Course; Education in Circuits, Applied Electromagnetics, Circuits and Systems

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1. Introduction

Circuit analysis is an important professional course mainly for the students in electromagnetic education. These students just touch university courses, too much systematic and esoteric knowledge is difficult to attract students attention. Besides, the traditional teaching methods generally regard theoretical knowledge as the focus of the entire semester. The equally important practical hands-on courses are placed at the end of the whole teaching process or be finished as a final report by students. Due to the forgetting of the theoretical knowledge and the difficulty of the final task, the students do not have sufficient basic knowledge and theoretical reserves to the experimental report so that students do not think enough about the entire teaching experiment and have their unique innovations in the course tasks, which leads to little gains in the learning of analog circuit courses. To get better quality of classroom teaching and deliver high quality integrated circuit talents to the country, it is necessary to take into account student’s knowledge absorption ability and improve learning enthusiasm in curriculum education. Therefore, this work proposes an innovative course teaching method of “self-learning as the mainstay, supplemented by circuit examples”, which allows students into the learning process of electronic circuits. The combination of theoretical knowledge and circuit examples can enable students to better grasp and digest the knowledge they have learned [1], [2], [3], [4]. The simulation tool Multisim is used in this course teaching method, which allows students to consolidate their knowledge and get in touch with the design and simulation of electronic circuits in advance, [5], [6].

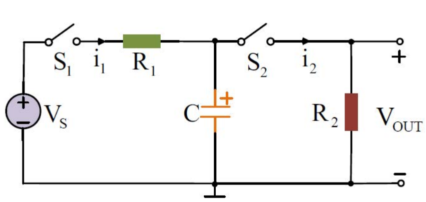

Fig. 1. The circuit of capacitor charging and discharging.

The innovation course teaching method combines specific circuit examples and theoretical knowledge to increase the interaction with students and improve student’s attention and enthusiasm. The simulation tool Multisim enhances student’s hands-on ability and broadens student’s thinking and exploration ability. Based on effective knowledge teaching, students can be more involved in the entire teaching process. This case study takes “capacitor charging and discharging analysis” as an example to describe this innovation course teaching method: Firstly, a specific problem in real life is introduced to elicit a related circuit example; Secondly, the key knowledge is reviewed again based on full preview before class; Next, a specific circuit is designed step by step based on the problem and the key knowledge; Finally, the software tool Multisim is used to simulate and analyze the designed circuit.

2. Innovative Course Learning Method

Traditional electronic circuit teaching methods spend much time on the detailed explanation of theoretical knowledge to ensure that students have a correct understanding of the knowledge of the book. In the entire traditional teaching process, the teachers only repeat the content on the presentation document, and the students can only learn passively and lack the opportunity to learn independently. This case study takes “capacitor charging and discharging analysis” as an example, the traditional electronic circuit teaching methods give the capacitor charging and discharging circuit shown in Fig.1 directly and conduct circuit analysis: During the capacitor charging period, the switch S1 is closed and the switch S2 is opened so that the capacitor C is charged by the power supply Vs through the resistor R1; During the capacitor discharging period, the switch S1 is opened and the switch S2 is closed so that the capacitor C is discharged through the resistor R2.

The traditional electronic circuit teaching methods give the circuit structure directly and explain the circuit characteristics.

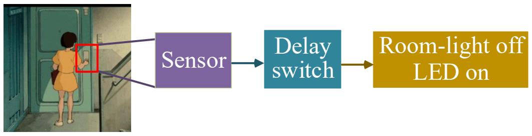

Fig. 2. Schematic diagram of the delay switch circuit.

The knowledge in the book is repeated in the traditional course teaching methods. The students have not learned knowledge outside the textbook so that there is no enthusiasm for learning by repeated knowledge. This proposed innovative teaching method abandons the traditional teaching method of “teacher only speaks, students only listen”, and divides the course teaching process into problem introduction, key knowledge review, circuit examples, and Multisim simulation.

2.1 Problem Introduction

With the rapid development of modern technology, advanced technology is increasingly applied to daily life, such as autonomous driving and home automation. In our daily life, we may encounter some problems of forgetting to turn off room lights and some other electrical appliances after going out, causing energy waste and even leaving safety hazards. To avoid these problems, a delay switch circuit is proposed here shown in Fig.2. When we go out to close the door, the sensor in the lock is triggered. The door-closing signal is transmitted by the sensor to the delay switch module. After a certain period, the lights or some other electrical appliances in the room shut down which reduces energy waste and eliminates safety hazards.

Before entering the class teaching formally, the common circuit example in daily life is introduced firstly so that students are exposed to the learning in this class and be guided to think about the relationship between the delay switch module and the capacitor charging and discharging. During the next course period, the students can follow the teacher’s teaching with questions and gradually solving their doubts by key knowledge “capacitor charging and discharging”, which can make the knowledge more specific and profound.

2.2 Key Knowledge Review

Since the proposed course teaching method needs to spend enough time on the analysis of specific circuit examples and simulation verification by the simulation tool Multisim, the teacher does not give a detailed explanation of the theoretical knowledge of the textbook. This class teaching method pays more attention to the process of students self-preparation and releases class pre-preparation homework in time. The students need to prepare and complete the pre-preparation report independently. The key knowledge and the problems encountered by the students during the pre-preparation process are organized into a specific document. This document is recorded in the usual grades. This class teaching method mainly lists the important key knowledge in the book on the presentation document, and the teacher guides the students to familiarize themselves with the key knowledge again and lay the foundation for the subsequent analysis of specific circuit examples. The animation schematic diagram of capacitor charging and discharging is shown in Fig.3.

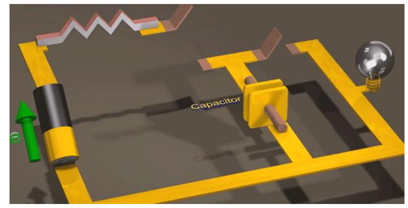

Fig. 3. The animation schematic diagram of capacitor charging and discharging.

This class teaching method takes “capacitor charging and discharging analysis” as an example to introduce the charging and discharging characteristics as an important energy storage element. As a basic component of integrated circuits, the capacitor is widely used in various fields. For example, capacitor as an energy storage unit is widely used in capacitive ADC arrays in SAR ADC, [7], (Successive Approximation Analog-to-Digital converter): During the SAR ADC sampling period, the input signal is sampled by the capacitive array and stored in the capacitor array in the form of charge; During the SAR ADC conversion period, the digital logic of the SAR ADC controls the switch array of the capacitive array to compare the input signal with the specific binary voltage thresholds.

In the key knowledge review, the three characteristics of capacitors are listed on the presentation document: (1) Capacitors store charge and electrical energy; (2) Capacitors block DC signals and pass AC signals; (3) Capacitor voltage can not be changed suddenly. After understanding the three characteristics of capacitors, the students are guided to review the capacitor charging and discharging circuit shown in Fig.1. Based on the full preview, the students are guided to review the circuit characteristics in Fig.1 simplify and consolidate key knowledge.

In addition to the boring review of capacitor charging and discharging circuits, animation demonstrations have also been introduced into this course teaching method. The animation demonstrates the charging and discharging process and describes the flow of charge and the change of the capacitor voltage during the charging process and discharging process. The animation demonstration also enables students to learn and consolidate the process of capacitor charging and discharging again, laying the foundation for the following specific circuit example analysis.

2.3 Circuit Examples

Circuit example analysis is an innovative part of this classroom teaching method. This proposed course teaching method designs relevant specific electronic circuits based on key knowledge and the introduced problems. The students are guided to conduct a circuit analysis step by step. The key knowledge is applied to specific circuit examples, which improves the circuit analysis ability based on familiar key knowledge again and also enhances the student’s enthusiasm in learning. At the end of the specific circuit example, a period is given for the students to raise questions about the

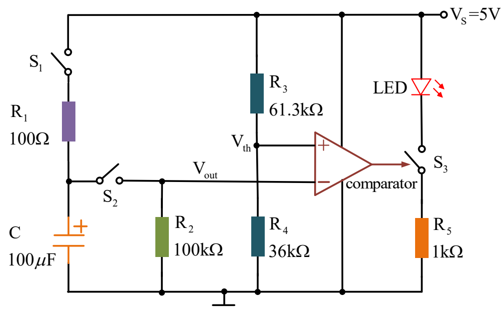

Fig. 4. Capacitive delay switch.

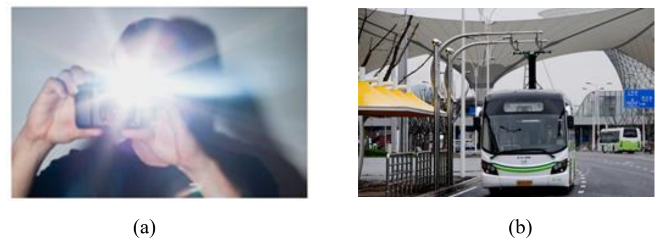

Fig. 5. Application examples of capacitor charging and discharging:(a) Camera flash; (b) Super-capacitor bus.

circuit example and discuss the raised questions in groups. The students give their own opinions about these problems and the teacher summarizes and answers these questions finally, [8], [9].

According to the delay switch diagram shown in Fig.2, this class teaching method designs a 10s capacitive delay switch module according to the circuit characteristics of capacitor charging and discharging. First, the capacitor discharging circuit is determined as the delay timer circuit and the time constant in the discharging circuit is equal to 10s; Then, a capacitor charging circuit is designed to store enough charge for the capacitor discharging circuit to discharge; Next, a comparator is introduced to compare the output voltage of the discharging circuit and the threshold voltage. When the output voltage of the discharging circuit is less than the threshold voltage, the output signal of the comparator is submitted in the next control module. Finally, the control signal of the comparator controls the switch close, thereby the LED light is on in the output circuit. The design circuit diagram of the entire delay switch is shown in Fig.4.

The circuit example of this course teaching method adopts the new teaching method of "first divided, then total". Taking the capacitive delay switch as an example, the whole design is divided into various modules and designed step by step firstly, and then these divided modules are combined to complete the total delay switch circuit: Firstly, the core part of the delay module should be designed first. According to the concept of the capacitor charging and discharging in the key knowledge review section, the time constant of the discharging circuit is used as in the time delay module, so the value of capacitance and resistance in the discharging circuit should meet the time constant of 10s. Secondly, the capacitor discharging circuit is used as a delay module, so a capacitor charging circuit is designed to quickly charge the capacitor for the capacitor discharging circuit. According to the review of key knowledge, the charging speed of a capacitor is related to its time constant. Therefore, it is determined to add a small resistance element to the capacitor charging circuit for fast charging. Thirdly, detecting when the discharge voltage of the capacitor discharging circuit falls at its time constant has also become a problem, so a voltage comparator is introduced. A threshold voltage is connected at the positive terminal of the comparator, which value is exactly the discharge voltage at its time constant of the discharging circuit, and then the output voltage of the discharging circuit is connected to the negative terminal input of the comparator, when the comparator detects the output voltage of the discharging circuit is less than the threshold voltage, a changing comparator output signal is obtained. Lastly, the switch controlled by the output signal of the comparator makes the LED light on in the output display circuit, and the whole design of the entire capacitive delay switch is completed. In this circuit example, the comparator module is used, which is particularly important for the basis of analog circuits. However, this course teaching method does not focus on the internal structure of the comparator but the characteristics of the comparator.

This course teaching method introduces two more application examples, one is the camera flash, and the other is the super-capacitor, as shown in Fig.5. The camera flash uses capacitor charging and discharging to quickly release the energy stored in the capacitor to produce a flash.

Ordinary capacitors have high discharging power, but the energy density of the ordinary capacitor is generally less than 0.1Wh/kg, which is difficult to be used as an energy storage element in real life. Therefore, the super-capacitor combines the high discharging power of the capacitor and the powerful charge storage capacity of the lithium battery. Super-capacitor is generally used in wind power pitch systems and super-capacitive battery systems for new energy vehicles. The super-capacitor bus applies super-capacitors to the energy storage system. Each time the bus stops and waits for guests to get on and off the bus, the super-capacitor bus extends the bracket to connect the platform power supply and the super-capacitive battery system for fast charging. In just a few tens of seconds of waiting time, the platform power supply can charge the super-capacitive battery system and the stored energy is far enough for the bus to drive to the next bus station.

This case study represents three common circuit examples of capacitors: capacitor delay switch module, camera flash, and super-capacitor application. The key knowledge learned in the classroom is quickly and accurately applied to actual application examples, which not only consolidate the learned knowledge but also enhance student's learning enthusiasm.

2.4 Multisim Simulation

Since the electronic circuit course is very practical, more students are required to complete the circuit design independently. If hardware experiments are used, there are the

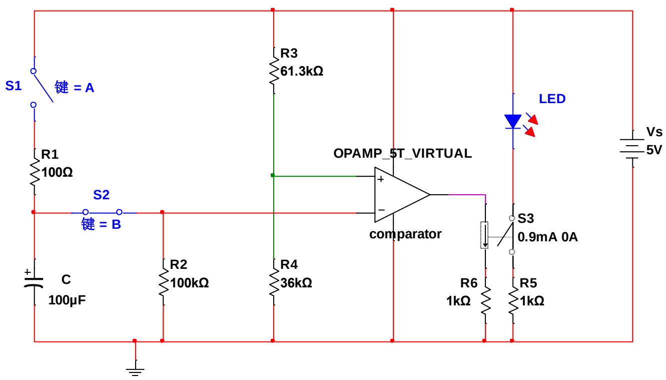

Fig. 6. Multisim simulation diagram of capacitive delay switch.

following problems: (1) Because the hardware components are too complex and the hands-on ability requirements are high that make students lack interest and initiative in learning; (2) Because students are not clear about the principle, there are contingency and blindness in the operation process, which causes a high damage rate to the equipment and make the experimental project fail to complete. Therefore, how to complete the simulation of circuit examples in a short time with high quality and quantity has become a problem that needs to be solved in classroom teaching. With the rapid popularization of computer technology, the use of computer simulation software to analyze, simulate, and optimize circuits has become an effective method. The use of Multisim software in the course teaching process not only reduces the experimental cost of course design but also greatly improves the classroom teaching efficiency and student's learning ability, which effectively stimulates student's interest in learning, [10], [11].

The use of Multisim can enable students to have a direct impact on circuit construction and circuit results before doing hardware experiments, and understand the impact of various circuit components in electronic circuits on the performance of the entire circuit. This enables students to have a deeper understanding of the experimental content and master the theoretical knowledge of electronic circuits. After the simulation experiment is completed, the circuit is built and tested on the test bench, and the simulation and measured results are compared and analyzed. Through the combination of simulation experiments and physical experiments, students can master common circuit solutions and improve their ability to analyze complex circuits. In the teaching method, the Multisim software helps students develop the learning habit of combining theoretical knowledge and simulation verification and lay a good foundation for the design of integrated circuits.

According to specific c apacitive d elay m odule i n t he last part, the students independently select the corresponding components to build the circuit and simulate in Multisim. The specific d elay s witch c ircuit i s s hown i n Fig.6.

Since a comparator is used in this circuit example that the students have not touched, the comparator model (OPAMP-5T-VIRTUAL) is given to reduce the interference problem in the process of building the circuit. During the circuit simulation process, the teacher walks around and observes the student's construction process. Finally, students organize the simulation circuit, simulation results, and problems in the simulation process into a specific document, which becomes a part of the usual performance assessment. Besides, the use of Multisim simulation software is difficult for students. Therefore, at the beginning of formal course teaching, one class time is used to lead students to familiarize and use Multisim software for subsequent course teaching.

3. Conclusion

Circuit analysis is the first professional course for freshmen in engineering education and an innovative teaching method of "self-learning as the mainstay, supplemented by circuit examples" is proposed in this work. This course teaching method repeats the key knowledge simply and designs a specific circuit according to a problem in real life, and the designed circuit is simulated by Multisim software, which can effectively improve a student's professional level and innovation ability. This proposed teaching method promotes student's knowledge learning and the effectiveness of simulation verification learning.

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