

Teaching with a Matlab simulation in the course Power Electronics Converter Technology

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ABSTRACT: Owing to the plentiful types of circuit and their complex analysis in the *Power Electronics Converter Technology* course, it is proposed in this article by Miaolei Zhou and Qi Zhang of the College of Communication Engineering at Jilin University, Changchun City, PRC, to assist the teaching by using the Matlab (Matrix laboratory) tools. Using the thyristor three-phase bridge full-wave controlled rectifier circuit as an example, a simulation model was developed using Matlab software. It is easy to produce simulation graphics under various load conditions and to analyse the various problems. The experiment demonstrates that students can quickly understand the theory and also learn to use the simulation to analyse a problem. This overcomes the problems of the traditional teaching mode by achieving the goal of teaching by experiment.

INTRODUCTION

Power Electronics Converter Technology is a compulsory course for the automatic control and power professional in higher education in China. It is a professional course with a strong theoretical and practical base [1]. The main components of this course are: grasping the structure of a variety of power electronic circuits; the working principles; control methods; design calculations and practical skills; and to be familiar with the scope of applications for the various power electronic devices, and other technical and economic matters [2][3].

The content of the course includes: AC/DC converter (controlled rectifier); DC/DC converter (DC chopper); DC/AC converter (inverter); AC/AC converter (AC voltage regulator). One of the main study areas is the analysis of voltage and current waveforms. The current teaching mode is by classroom teaching and experiments. The experiments consolidate and deepen the understanding of students' classroom learning.

Most of the schools adopt the *pendant structure* (i.e. using a hand-held device) or test chamber by which to do the experiments using packaged circuits and systems. Students connect wires as shown in pictures in the guide book, and record the experimental data and waveform. This method does not require initiative or a positive approach by the student. It does not improve the ability to analyse or solve problems, and is not a good approach to experiments.

Once a result appears to be inconsistent with a theoretical solution, most students find it difficult to identify the cause of the problem and lack the ability to resolve the problem. One reason for this is that it is not enough to simply have some knowledge. Another reason is that there are too many laboratory equipment packages for students to fully understand. Hence, if there are problems in an experiment, most students will not be able to resolve them.

In order to overcome these problems, computer simulation technology has been introduced into the traditional teaching method using the Matlab tool [4]. Matlab has been used widely in teaching work [5-9]. The software simulates the working of circuits and allows these circuits to be modified by varying parameters; hence, producing various waveforms. This improves the quality of teaching by making the abstract concrete, the boring interesting, and stimulates students' interest.

SIMULATION TEACHING EXAMPLES

The thyristor three-phase bridge full-wave controlled rectifier circuit (see Figure 1) is a typical form of AC/DC conversion and it is an important type of circuit [4]. The function of this circuit is to convert three-phase AC power into DC power, with the average value of the output voltage changeable by use of a three-phase controllable rectifier bridge arm. The output value is controlled by the thyristor conduction angle. The output of the circuit relates to the load, which

generally includes a pure resistor load, an inductive resistance load and back electromotive force load. The inductive resistance load is divided into high inductance and low inductance. So, there are four main circuit structures.

The teaching focuses on the analysis of the workings of the four kinds of thyristor circuits; the voltage across the load; and the current waveform. Explanations need to take into account the different states among at least eight working modes of the four circuits: the on-off state of the VT1 to VT6 of the six thyristors, trigger pulse sequence; when the load is pure resistive load, inductive load or back electromotive force load; how the output rectifier voltage and current waveform change (Figure 1).

Overall, the situation is very complex and it is very difficult for teachers to convey so much knowledge. Equally, it is difficult for students to understand and master so much information in the classroom.

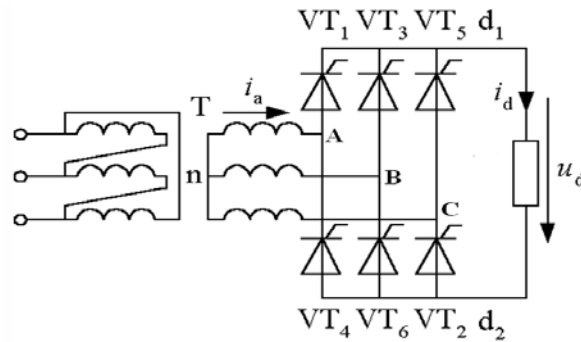


Figure 1: Thyristor three-phase bridge full-wave controlled rectifier circuit.

Therefore, simulation teaching was introduced. For each case, the voltage and the current of the rectifier circuit output can be graphically displayed while, at the same time, having a clear understanding of the pulse trigger circuit state. Figure 2 is a simulation model of the thyristor three-phase bridge rectifier circuit.

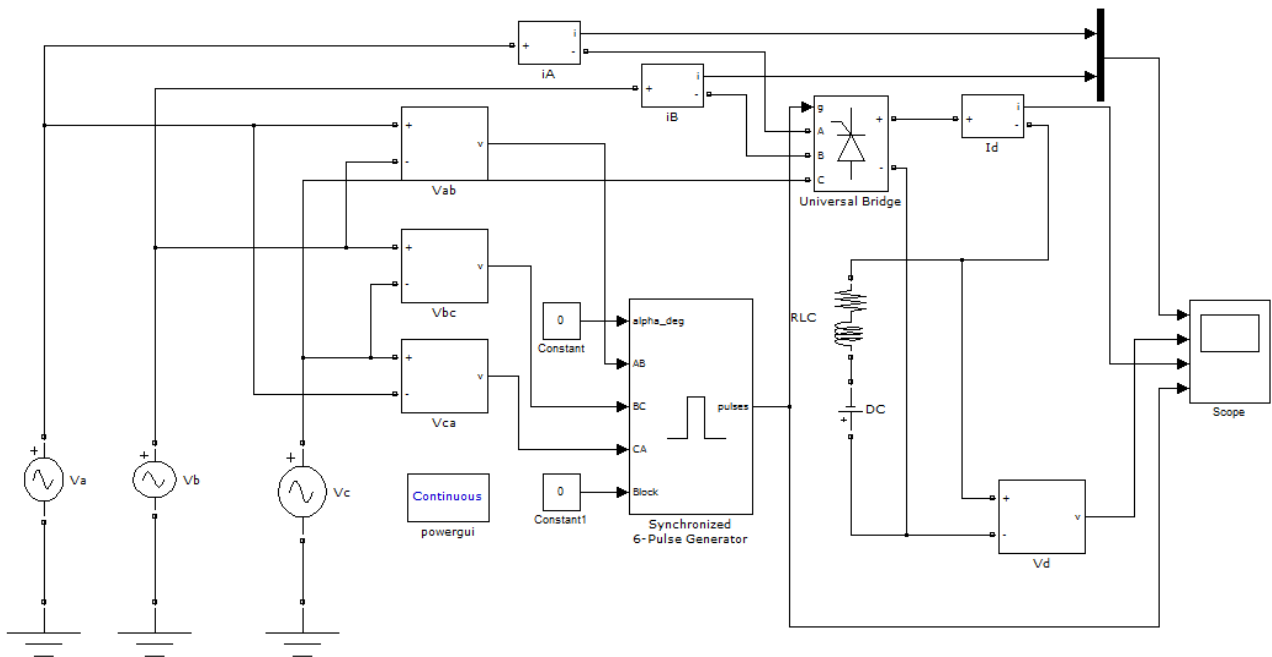


Figure 2: Simulation model of the thyristor three-phase bridge rectifier circuit.

Rectifier Bridge Model

The Rectifier Bridge is the core unit of the thyristor three-phase bridge rectifier circuit, which is simulated using the Universal Bridge module in the Matlab SimPowerSystems toolbox. This module has four input terminals and two output terminals.

Wherein: A, B, C terminals are input terminals of the phase voltage of the three-phase AC power supply, and the g terminal is the trigger input terminal. +, - terminals: the output and input terminals of the rectifier circuit, which form a loop in the model. Parameter settings are shown in Figure 3.

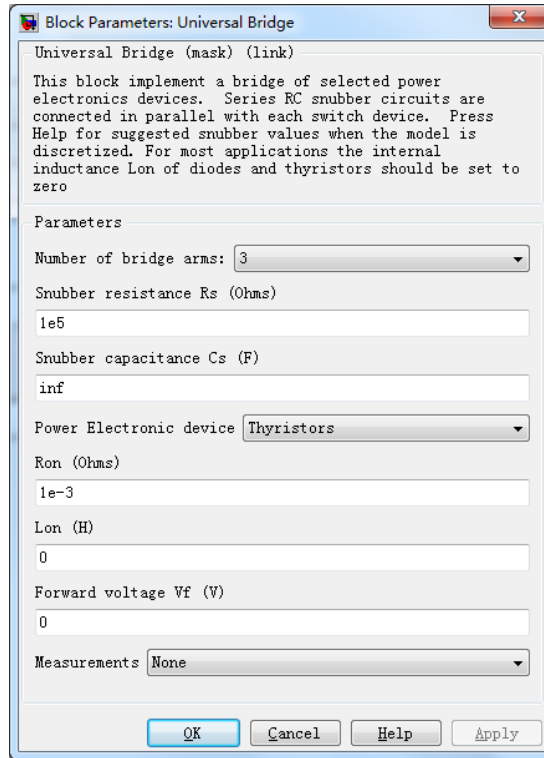


Figure 3: Parameter settings of the universal bridge module.

Synchronised 6-Pulse Generator

The synchronised 6-pulse generator is used for triggering the six thyristors of the thyristor three-phase full-wave controlled bridge rectifier circuit. It has five inputs and one output terminal. Alpha_deg is the input terminal of the pulsed triggering angle control signal. AB, BC, CA, is an input of the three phase voltage of the three-phase power, i.e. Vab, Vbc and Vca.

Block is a triggered control terminal, and its value is zero to open triggers, while the value is zero plus to turn it off. Pulses are through the pulse output signal terminal, which is connected to the pulse input terminal of the three-phase bridge rectifier circuit. Parameter settings are shown in Figure 4. The frequency of synchronisation voltage is 50 Hz, pulse width is 10. The checkbox of double pulsing is selected.

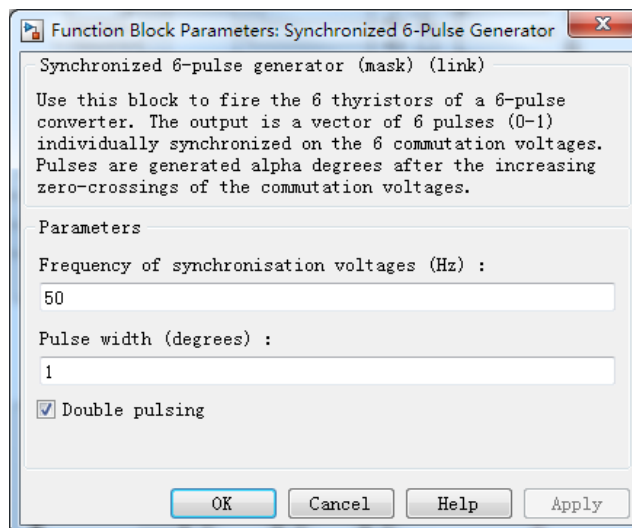
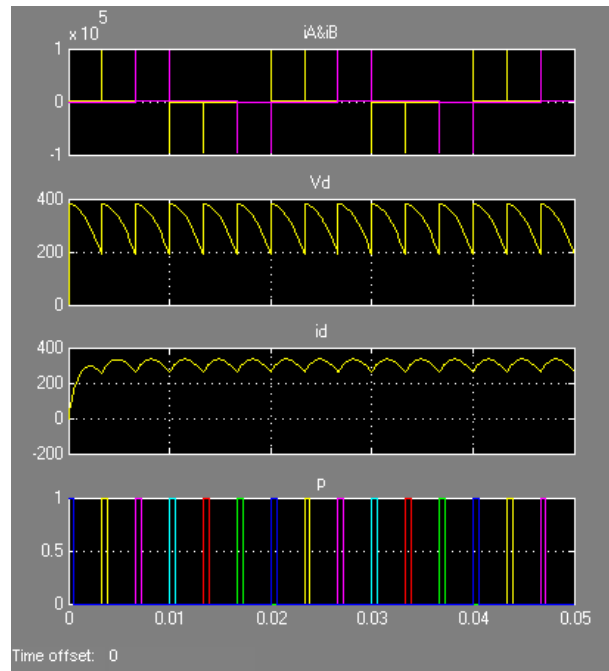
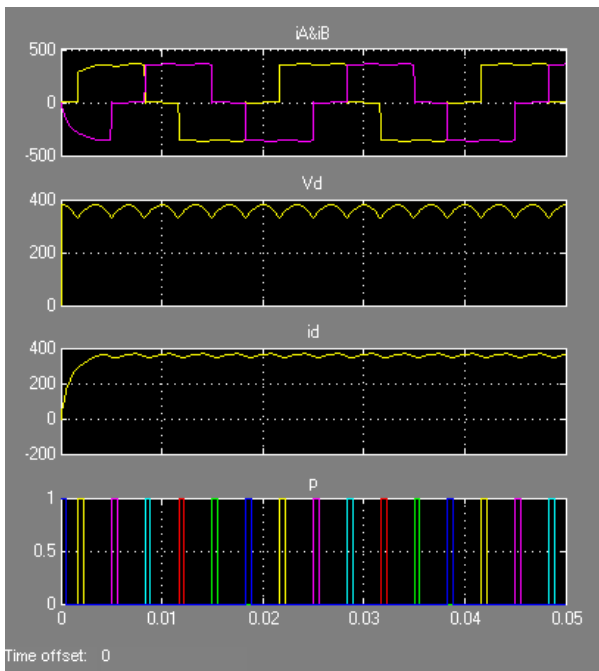


Figure 4: Parameter settings of the synchronised 6-pulse generator.

Simulation Results

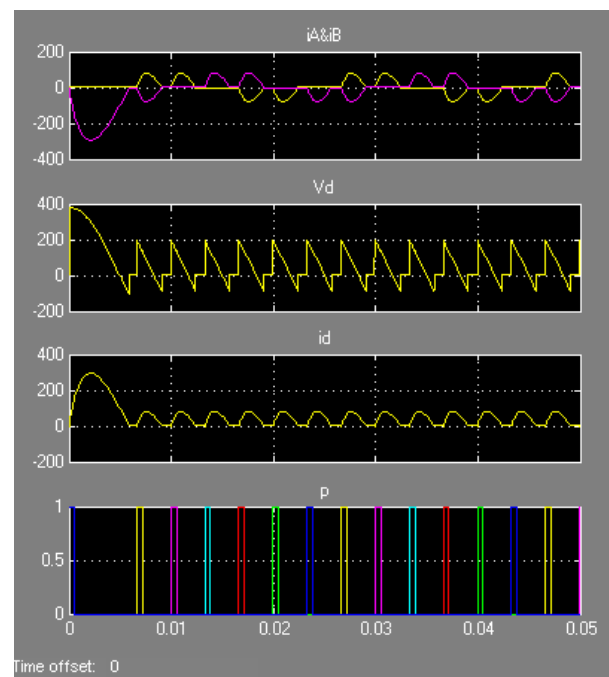
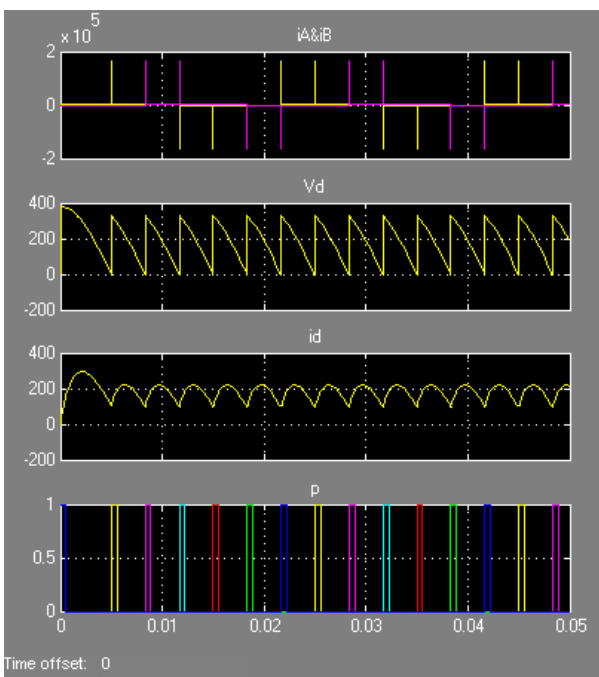
The simulation algorithm ode23; the simulation time is 0.00-0.05s; other parameters are the default values. By setting the value of the inductance L, resistance R and the value of the back electromotive force V, the four kinds of circuit are easily obtained. By setting the value of the alpha_deg parameter, the size of the phase shift control angle is easily set, and the output waveform of the rectifier circuit is obtained.

Figure 5 is the waveform of i_A & i_B , load voltage V_d , load current i_d and synchronised 6-pulse generator p when the trigger angle is 0° (see Figure 5a), 30° (see Figure 5b), 60° (see Figure 5c) and 90° (see Figure 5d), The load parameters are $R = 1 \Omega$, $L = 1 \text{ mH}$, back electromotive $V = -5 \text{ V}$.



a)

b)



c)

d)

Figure 5: Waveform of the system output voltage and current: a) trigger angle is 0° ; b) trigger angle is 30° ; c) trigger angle is 60° ; and d) trigger angle is 90° .

In addition to the conventional theoretical waveform, Matlab also can simulate a circuit fault. From past teaching experience, it was found that if there were no graphics similar to the ones shown in the experimental guide book, most students will not analyse the reasons for the fault. Problems can be demonstrated to students through a simulation experiment, making it easier to identify the cause of the problem.

For example, the rectifier circuit output waveform will change when the thyristor damage appears in the A phase in the experiment (in Figure 6, for example, the trigger angle is 0°). In previous experiments, many students did not know the cause of the problem when this occurred in an experiment. Through the use of Matlab simulation teaching, students will

know the reason from the graphics on the A-phase thyristor damage or thyristor VT1, i.e. a branch connection is not properly connected or A-phase voltage disappears.

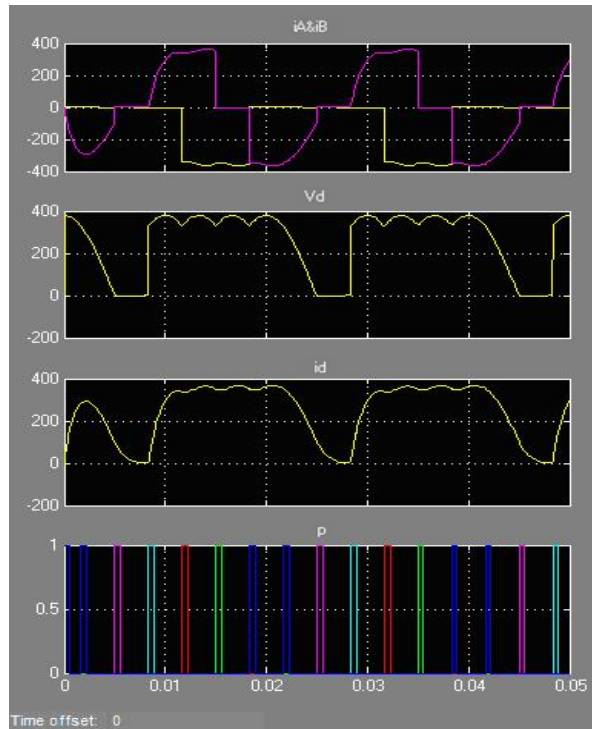


Figure 6: Rectifier circuit output waveform when the circuit has an error.

TEACHING EFFECT COMPARISON

In order to test the effect of improved teaching methods, the authors analysed two groups of students who took part in the experiment. The content of the experiment was the three-phase full-wave controlled bridge rectifier circuit. Group A used Matlab simulation teaching, while Group B did not use the Matlab simulation teaching. There was a total of 60 students in each group. Experimental results show that the average time for completion of the experiments of the first group of students is much shorter than for the second group of students.

When the experimental circuit produced the two waveforms shown in Figure 4 and Figure 5, there were 43 students who were able to find the cause in one minute in the first group, occupying i.e. 71.67% of the total, and there were 57 students able to find the cause in three minutes, i.e. 95% of the total. There were 26 students who were able to find the cause in one minute in the second group, occupying i.e. 43.33% of the total, and there were 38 students being able to find the cause in three minutes, i.e. 63.33% of the total. The experimental results are shown in Table 1.

Table 1: Two sets of comparative experimental data.

	The number completing within 90 min	The time of completion	The number finding the cause within 1 min	The number finding the cause within 3 min
Group A	59	73 min	43 (71.67%)	57 (95%)
Group B	47	82 min	26 (43.33%)	38 (63.33%)

CONCLUSIONS

The authors of this article have researched the effectiveness of teaching using Matlab software and taking the three-phase bridge rectifier circuit as an example. The Matlab simulation technology also can be used to teach students about the chopper and inverter circuit. Through combining Matlab and power electronic converter technology with the multimedia courseware, no real hardware environment and resources are required.

Presentation directly in the classroom allows students to see the real-time simulation results and to increase their awareness. Results from the teaching of practical sessions show that the teaching methods used in this article can reduce learning difficulties of the Power Electronics Converter Technology course and better stimulate students' interest in learning, while developing their ability to solve problems at the same time. That is, a simulation analysis should be performed first to determine the feasibility and possible results; then, the actual design undertaken; thus, improving the

learning efficiency and the quality of teaching. Students' initiative, practical ability and innovative thinking were strengthened in achieving the teaching objectives.

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