# Frequency Converter Case Study to Guide the Teaching of Power Electronics and Electrical Drives Course Cluster

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**Abstract: Integrating case into the teaching of the power electronic and electrical drives course group will guide students to sublimate the knowledge of multiple disciplines organically into a knowledge system. The frequency inverter case is decomposed into motor body structure, speed control method, speed control main circuit, control method, equipment development, respectively. This can guide the teaching of electrical machine course, power electronic technology course, power drag automatic control system course, embedded development technology course to build a multi-dimensional, multi-temporal course group teaching system, which is conducive to the continuous reduction of teaching hours in the context of improving students' understanding of the theoretical knowledge of the various courses and the construction of the knowledge system of the power electronics and electrical drives course cluster.**

**Keywords: Power Electronic Technology; Electrical Machine; Power Drag Automatic Control System; Drives Course Cluster; Embedded Development Technology; Course Group; Teaching Case; Knowledge System**

## 1. Introduction

Electrical machine course, power electronics technology course, power drag automatic control system course, embedded development technology course and other courses are the main courses in the direction of power electronics and electrical drive courses. Electrical machine course mainly teaches the basic structure of AC and DC motors, equivalent circuit, parameter calculation equation, speed control methods and other theoretical knowledge. Power electronic technology course mainly teaches rectifier circuits, inverter circuits, chopper circuits, AC/DC converter circuits, as well as combinational circuits and other theoretical knowledge. Power drag automatic control system course mainly teaches double closed-loop speed control system, asynchronous motor steady state model and dynamic model, vector control and direct torque control method, synchronous motor control and other theoretical knowledge. Embedded development technology course mainly teaches microprocessor, analog-to-digital conversion, keyboard and display, communication and other hardware and software knowledge.

In the current teaching, the knowledge of each course is arranged and revised independently, and there are more same knowledge points among the knowledge of each course, for example, there are DC motor and AC motor equivalent circuits and parameter expressions in the power drag automatic control system course, as well as rectifier circuits, inverter circuits and other power electronic main circuits, and the embedded device block diagrams of the general-purpose frequency converter are also given. In the process of teaching, students often do not understand the knowledge of a course in the practical use, the links between the courses is also difficult to organically combine to form a knowledge system, not to mention the ability to use embedded technology to develop relevant practical equipment. Having forgotten what has already been learned while taking a new course, having to reteach what has already been learned in a new course makes the instructional hours less plentiful. In the current context of constant compression of teaching hours, the intellectual capacity of students continues to decline. In the graduation design students do not have practical hands-on ability, the effect of the graduation design is poor.

 

Extensive research and practice has been undertaken by teaching staff to address this paradox. Case-based teaching has been applied by the majority of teachers, applied in the teaching of many courses to stimulate students' interest in learning and enhance the learning effect, but most of them are limited to the teaching of a single course, and further research is needed to enhance the entire knowledge system [1-5].

In order to enhance the students to meet the needs of enterprises, the teachers carried out the construction of teaching system based on practical engineering, analyzed the needs of enterprises from the perspective of enterprises, and put forward the integrated curriculum system and specific implementation suggestions [6,7].

In order to enable students to improve their engineering innovation ability, the teachers put forward the talent cultivation concept of science-education fusion and project-driven, establish an integrated curriculum system with innovation ability cultivation as the main line, and set up an all-round cultivation system of engineering application and innovation talents in terms of teaching methods, practical teaching mode and platform construction [8,9].

In order to improve the cultivation level of undergraduates of our electrical engineering and automation program, we have integrated the concepts of case study teaching and science and education fusion, and cultivated talents who can be brought to the demand of ready-to-use enterprises from the concept of export- and result-oriented teaching. Combined with the engineering needs of new energy electric vehicles, we take inverter equipment development as a chain, break through the barriers between the courses of electrical machine course, power electronic technology course, power drag automatic control systems course and embedded development technology course, reforms in terms of content planning, scheduling, teaching methods and technology, and cultivate engineering application innovative talents with the ability to independently develop inverters.

## 2. Course Cluster General Knowledge Points

There are numerous common knowledge points between multiple courses, and clarifying these knowledge points helps to rationalize the teaching of these knowledge points so as to maintain the integrity of teaching within the ever-compressed teaching hours. The common knowledge points between several courses of electrical machine course, power electronic technology course, embedded development technology course, and power drag automatic control systems course are shown in Figure 1.

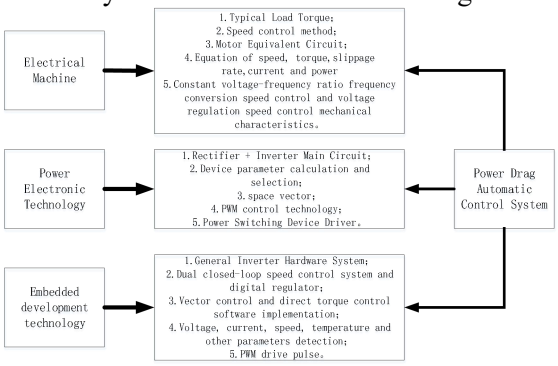


**Figure 1. General Inverter Knowledge Map**

Electrical machine is a basic course for Electrical Engineering and Automation majors, which includes knowledge about transformers, DC motors, AC motors, synchronous motors, and so on. The structure of AC and DC motors is given on the one hand in the course of electrical machine, along with equivalent circuits for characterization, and equations for calculating speed, torque, induced potential, and so on.

The equation for the speed of an asynchronous motor is given in the electrical machine course as follow:

$$n = \frac{60 f_s}{n_p}(1-s) \tag{1}$$

The air gap flux induces an electromotive force in each phase of the stator winding with an effective value of:

$$E = -j4.44 f_s N_s K_s \Phi_m \tag{2}$$

Constant electromotive force frequency ratio is often maintained in motor speed regulation in order to maintain a constant magnetic flux.

In addition, electrical machine course gives equations for starting torque:

$$T_e = \frac{3 n_p U_S^2 R_r / s}{\omega_s \left[ \left( R_s + R_r / s \right)^2 + \left( X_{s\sigma} + X_{r\sigma} \right)^2 \right]} \tag{3}$$

The maximun torque is

$$T_{e\max} = \frac{3 n_p U_s^2}{2\omega_s \left[ R_s + \sqrt{R_r^2 + \left( X_{s\sigma} + X_{r\sigma} \right)^2} \right]} \tag{4}$$

The starting torque is

$$T_{est} = \frac{3 n_p U_S^2 R_r}{\omega_s \left[ \left( R_s + R_r / s \right)^2 + \left( X_{s\sigma} + X_{r\sigma} \right)^2 \right]} \tag{5}$$

 

These expressions are also the subject of the power drag automatic control systems course.

Electrical machine course also introduces three typical load characteristics in social production: constant torque loads, constant power loads, fans and pumps loads, as well as the mechanical characteristics of constant-voltage-frequency-ratio variable-voltage frequency-variable-speed regulation and the mechanical characteristics of voltage-regulated speed regulation.

Power electronics technology provides electrical energy conversion technology for many electrical engineering applications, for new energy electric vehicles and other motor speed control applications, the main circuit of the inverter includes the rectifier and inverter main circuits in power electronics technology, and at the same time in the design of the inverter, the calculation of the parameters in the main circuit and the selection of the devices are the important knowledge points of the power electronic technology course. The concept of space vector is introduced in voltage inverter circuits, while the effective voltage vector of three-phase voltage inverter circuits is given, as well as the new technology of PWM control. The drive technology itself is one of the key knowledge points of power electronics.

The main circuit of the inverter, shown in Figure 2, has a combination of three-phase uncontrolled rectifier and three-phase voltage-type inverter circuit, which is one of the typical applications of power electronics courses, and also one of the mandatory knowledge points of the course of automatic control system of electric power traction, and the diode, IGBT, capacitors and other devices in the main circuit, such as the calculation of the parameters of the device and the selection of the device is one of the contents of the two courses of engineering teaching.

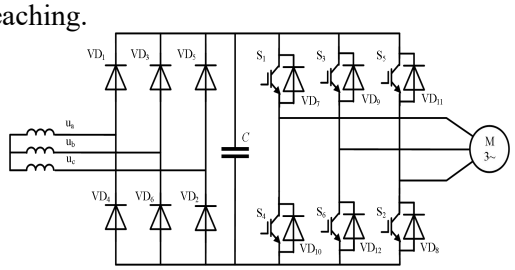


**Figure 2. AC Motor Inverter Main Circuit**

Electrical machine course teaches the basic theory of motor, power electronics technology course teaches the main circuit, power drag automatic control system teaches the control method, on the basis of these basic theoretical knowledge, but also with the help of embedded development technology in order to transform the theoretical knowledge into equipment, in order to apply the new energy electric vehicles and other social enterprises, to create productive capacity, so that the students really have the ability to research and development of engineering practice.

With the rapid development of embedded technology, electronic technology and computer technology, the inverter system with the double closed-loop regulator, vector control algorithm, direct control algorithms, etc. need to be digital software programming to achieve, no longer need to be electronic circuits constitute the regulator. The regulator cannot be separated from the feedback, the collected voltage, current, speed and other signals need to be converted into digital signals by analog-to-digital converter to be sent to the MCU, and the soft regulator is used to output the PWM drive pulse to control the work of the voltage-type inverter circuit. Embedded development technology is the key course of inverter hardware realization.

The hardware principle of a general-purpose digital inverter for speed regulation of asynchronous motors is shown in Figure 3. In addition to voltage, current, temperature detection and PWM drive pulses, the digital processor is also configured with interfaces such as display, keypad, communication, and control output signals for suppressing the pump-up voltage.

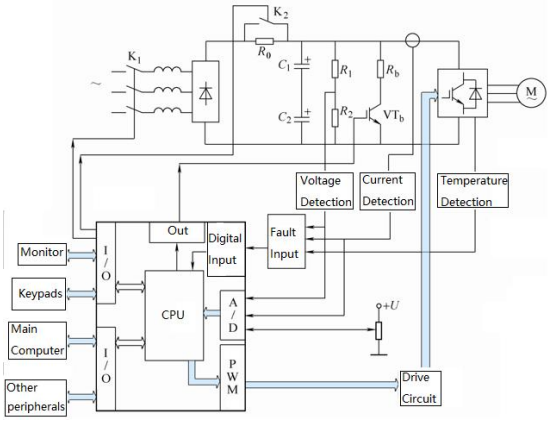


**Figure 3. Digital General-purpose Inverter Hardware Schematic**

## 3. Teaching Content Planning

In order to fit into the broader context of

compressed credit hours, the generalized instructional content shown in Figure 1 needs to be categorized into the appropriate courses, thus avoiding duplication of knowledge between courses.

Typical load characteristics are categorized into electric power traction automatic control system course, motor equivalent circuit and voltage, current, torque, magnetic chain, power, equation of motion are categorized into electrical machine course, motor speed control methods and speed equations are also categorized into electrical machine course, the natural mechanical characteristics of the motor are also categorized into electrical machine course, while the constant voltage-frequency ratio and voltage- and speed-regulation mechanical characteristics are categorized into electric power traction automatic control system course.

The main speed control circuit, parameter calculation, device selection, PWM control technology, and drive circuit are all categorized under power electronic technology course, while the space vector is categorized under power drag automatic control system course.

Inverter hardware system composition, double closed-loop speed control system and digital regulator, vector control algorithm, direct torque control algorithm, etc. are categorized into power drag automatic control system course, and PWM output pulse, real-time detection of each physical parameter, etc. are categorized into embedded development technology course.

## 4. Teaching System and Methodology

In the usual teaching, electrical machine course and power electronic technology course are offered in the same semester, while embedded development technology course is offered in the next semester, and the power drag automatic control system course is postponed for another semester, which has caused some problems in the learning process: when learning power electronics related circuits, the knowledge of DC speed control and AC speed control of electrical machine has not yet been explained; when explaining the embedded development technology, the students have not yet established the concept of hardware system composition of inverter; in the power drag automatic control system course, the students have already forgotten the power electronic technology and electrical machine related knowledge points seriously, resulting in having to take up a large number of hours to repeat the relevant knowledge of electrical machine course, power electronic technology course, embedded development technology course, which makes it impossible to complete the teaching of multiple knowledge points of the power drag automatic control system course as a result of the lecture.

### 4.1 Teaching Schedule for Course Clusters

In order to avoid the forgetting of students' knowledge points and the articulation of knowledge points between course clusters, the teaching semester arrangement of each course is improved. Electrical machine course and power electronic technology course can still be studied in one semester, the power drag automatic control system course and embedded development technology course are placed in one semester, and then the time of knowledge point explanation between the courses is carefully planned in one semester, while the interaction between the courses is enhanced.

### 4.2 Inter-course Knowledge Presentation Schedule

Due to the electrical machine course and power electronic technology course in a semester, and the original electrical machine course will often explain the transformer first, and then in the explanation of DC motors, AC motors, synchronous motors and other sequential explanations, and power electronic technology course will soon explain the rectifier circuit and inverter circuit, resulting in not explaining the speed control before the inverter has begun the main circuit of the explanation, resulting in difficulties in the learning of the students, and therefore need to be taught in sequence and time. Therefore, the teaching sequence and time need to be improved. The knowledge points of DC motor and AC motor will be explained in advance in electrical machine course, while power electronic technology course will be delayed for one month after the start of electrical machine course, so that the knowledge points of the two courses can be explained in a good order in time, and the mastery degree of students on the knowledge of frequency converter can be improved.

 

Embedded development technology course and power drag automatic control system course are arranged in a semester. Embedded development technology course first explain the basic knowledge, and power drag automatic control system course first explain the inverter hardware system composition. After understanding of the inverter hardware composition, students understand that the inverter needs to carry out the voltage, current, temperature and other parameters of the measurement of the inverter, the embedded technology course explains the analog-to-digital converter, can be the hardware peripheral circuit organic connection, to help students establish the concept of learning to use, but also with the application of purpose and engineering cases to learn hardware, improve the learning interest and learning effect.

After learning the control methods of double closed-loop, vector control and direct torque control in the power drag automatic control system course, the students have basically learned the relevant knowledge of software programming in the embedded development technology course, and then the software programming realization methods of double closed-loop, vector control and direct torque control are taught directly in the power drag automatic control system course, so that on the one hand, the software programming will be applied to engineering practice, and on the other hand, the software programming ability and programming interest of students is improved.

Through the adjustment of the course teaching time and knowledge teaching order, will constitute the inverter of the attention of the knowledge points according to the theory - the main circuit - the hardware system - the peripheral detection circuit - the control method - the software implementation of the order of the organic series together, enhance the learning to use, sublimation of the knowledge system, the ability to innovate in engineering practice, the effect of export-oriented training of personnel, through the compression of the latitude of time to avoid the forgetting of the learning of the past and the redundancy of the knowledge points. Through the compression of time latitude to avoid learning before forgetting, the redundancy of repeated lectures, improve the efficiency of teaching and learning.

### 4.3 Teaching Methods and Techniques

The rationalization of teaching practices and the order in which knowledge points are explained should also be complemented by teaching methods to further enhance the effectiveness of teaching.

In the explanation of electrical engineering, the electromagnetic field inside the motor, especially the rotating electromagnetic field of AC motor under three-phase power supply is an abstract knowledge, which is not easy for students to understand. Electromagnetic field numerical analysis software is introduced in the explanation of electrical engineering, the electromagnetic field of asynchronous motors, permanent magnet motors and other electromagnetic fields under the three-phase power supply is simulated, and the electromagnetic field animation in the operation of the motor is given, which can cognize the distribution of the electromagnetic field inside the motor from the visual perception, and improve the learning effect. That is to say, learning the knowledge of electromagnetism also helps to understand the distribution characteristics of the internal magnetic chain of the motor in the case of inverter power supply in the automatic control system of power drag.

The introduction of simulation technology in power electronics, rectifier + inverter, and then build a simulation model with the motor as a load, although no specific control algorithms are introduced, in the open-loop situation and can also be observed with an oscilloscope voltage, current, speed curves, that is, to help students understand the working principle of the rectifier circuit and the inverter circuit, but also more than the study of the calculation of each parameter of the equation in the mechanics of the motor.

Embedded development technology learning difficulties is the need to pass a large number of hardware circuit design and software programming in order to have the ability to develop engineering practice equipment, and teaching hours are limited, it is difficult to meet the requirements. Therefore, the introduction of simulation tools in the embedded development technology explanation, directly with the PROTEUS software to build hardware circuit schematic,

 

write the program, and then run and display, to achieve the exercise of hardware design and software programming capabilities, but also to a certain extent through the simulation to learn the realization of the inverter.

In order to enhance the learning effect of speed control methods such as double closed-loop, vector control, direct torque control and so on in the automatic control system of power drag, simulation technology is introduced, through which the time domain waveforms of torque, speed and current can be directly observed, and at the same time, the design method of PI regulator can be mastered, which lays the foundation of the engineering practice research and development. Then, on the basis of embedded PROTEUS drawing the main circuit, detection circuit and driving circuit of the inverter, as well as initialization, A/D acquisition and other basic software programming, the program of PI regulator, vector control and direct torque control is compiled, and the motor speed regulation is simulated, so as to further master the speed regulation methods.

## 5. Conclusion

Taking the development of new energy electric vehicle drive inverter as a case study, it organically connects multiple courses such as electrical engineering, power electronics, power drag automatic control system, embedded development technology, etc., and at the same time optimizes the arrangement of the same knowledge points in each course, and at the same time optimizes the time of the course group start time and the time of the explanation of the knowledge points in each course, so as to realize that, in the context of compression of the course credit hours, it does not curtail the teaching content, to Enhance the teaching effect.

Through the improvement of teaching technology and teaching methods, various simulation techniques have been introduced into traditional teaching to help students understand the abstract electromagnetic field inside the motor, to help students master the ability to use simulation tools to study algorithms, and to enhance the students' ability to research and develop and innovate engineering practice equipment.

Through the case-oriented teaching system reform of the course group, laid the students' theoretical knowledge ability and practical hands-on ability to improve for the later smooth implementation of the motor speed control large experiments, frequency conversion speed control Bijie topic of the completion of the degree, improve the learning to use, export-oriented talent training effect.

## Acknowledgments

This paper is supported by Ministry of Education Collaborative Education Program: “Construction of a multidimensional teaching system of electrical engineering for the electric vehicle industry”.

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