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Discussion on the Reconstruction of Electrical Engineering Undergraduate Teaching Scheme Facing the New Generation Power System

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With the construction of a new generation of electric power systems with new energy as the main body, there are major changes in the traditional electrical engineering undergraduate teaching system. On the one hand, the dynamic operating characteristics of the power system dominated by new energy sources and dominated by power electronic equipment will be significantly different from the traditional power system dominated by synchronous generators. Therefore, there is an urgent need to reform the curriculum system to train electrical engineering professionals who can adapt to the future development trend of the power system. On the other hand, with the rapid advancement of advanced information technology in recent years, the application of cutting-edge technologies such as cloud computing, big data, and artificial intelligence in the field of electrical engineering has become more and more in-depth. Therefore, there is an urgent need to cultivate advanced technical experts who possess more advanced information theory and cybernetics knowledge and master the application of cutting-edge information technology in the field of electrical engineering. From the perspective of student training and professional construction needs, this paper systematically analyzes the lag of the traditional electrical engineering curriculum system, and analyzes the knowledge needs of electrical engineering students adapting to the development of the new generation of power systems. From the perspective of teaching schemes, curriculum systems, and evaluation systems, a plan for restructuring the teaching system was proposed. The work in this article can provide a reference for the training of college students majoring in electrical engineering, and it can also provide a more feasible improvement idea for the training of college students in other majors.

Keywords: electrical engineering teaching scheme, reform in education, curriculum system, undergraduate education, new generation of power system

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1 INTRODUCTION

The Paris Agreement on climate change (Preston, 2021) charts the course for the world to transition to green and low-carbon development. On 22 September 2020, Chinese President Xi Jinping delivered an important speech at the 75th United Nations General Assembly, stating: China aim to have CO_2 emissions peak before 2030 and achieve carbon neutrality before 2060 (The Xinhua News

Agency, 2020). Driven by the goal of "green and low-carbon development," it will promote the transformation of renewable energy to the main energy source (Shu, 2021). According to statistics, China's total electricity consumption is expected to increase from 7.5 trillion kWh in 2020 to 15–17 trillion kWh in 2060 (Global Energy Internet Development Cooperation Organization, 2021). Renewable energy will become the main force in the supply of electric power. It is estimated that by 2030, the installed capacity of wind power and photovoltaics will exceed 1.6 billion kilowatts, and the power generation of renewable energy will be about 3.5 trillion kilowatt-hours (China Energy Research Association, 2020). After 2030, traditional non-fossil energies such as hydropower and nuclear power are constrained by resources and sites, and construction will gradually slow down, and the development of renewable energy will further accelerate. It is estimated that by 2060, the installed capacity of wind power and photovoltaics will exceed five billion kilowatts, accounting for more than 80% of the installed capacity, and the power generation of renewable energy will exceed 9.6 trillion kWh, accounting for more than 60%, becoming an important support for the power system (Peng, 2021). Obviously, the new power system with a high proportion of renewable energy will be the core development direction of the future energy system, which will bring great challenges to the traditional power system:

1) The ultra-high proportion of renewable energy is connected, the uncertainty faced by the system is further increased, and the balance of power and electricity is under great pressure (Hou et al., 2019; Impram et al., 2020). Renewable energy has strong uncertainty, and the randomness and volatility of its output will bring huge pressure to the power and power balance of the power system (Niu et al., 2022). Especially in extreme conditions such as earthquakes, bad weather, and sudden disasters, it is difficult to ensure Stable supply of electricity.
2) With a large number of power electronic devices connected to the power grid, the inertia of the power system is greatly reduced, and safe and stable operation faces great challenges (Muzhikyan et al., 2017; Peng et al., 2018). With the orderly withdrawal of conventional thermal power units and the grid connection of large-scale renewable energy sources, as well as the commissioning of a large number of transmission equipment containing a high proportion of power electronic components, the inertia of the future power system will inevitably be greatly reduced (Fernández-Guillamón et al., 2019). The system frequency regulation capability will be significantly reduced, which will subvert the existing system control operation mode and threaten the safe and stable operation of the power system.
3) It is difficult for traditional large power grids to meet future power transmission needs. For a long time, China's wind power and photovoltaic resources and loads have been distributed inversely. The northwest region is rich in wind power and photovoltaic resources, but has a sparse population and low power consumption; while the eastern region has few wind power and photovoltaic resources, but is densely populated and has a high level of power consumption. China connects resource areas such as northwest China with load areas in central and eastern China through the construction of UHV transmission channels (Zhang and Li, 2009). With the increasing demand for electricity in the eastern region, the scale of power transmission in the future will reach the level of trillions of kilowatt-hours, a large number of UHV power transmission channels are required to be constructed, which will result in huge costs.

It can be seen that in order to truly implement China's national "green and low-carbon development" strategy and to utilize renewable energy such as wind power and photovoltaics on a large scale, there are still many practical difficulties to overcome. How to solve these difficulties? State Grid Corporation of China (Xin, 2021) and China Southern Power Grid Corporation (Rao, 2021) have, respectively put forward action plans for building new generation of power system after research. Among them, the main points include the following:

1) Empowerment of digital technology to form an energy Internet that integrates multiple energy sources (Wu et al., 2020). With the prominent features of distributed production and distributed utilization of energy (Yan and Hu, 2018), by deepening the integration and application of advanced information and communication technology, control technology and energy technology (Zhang, 2021), driven by digital technologies such as cloud computing, big data, and the Internet of Things, the smart grid will evolve into a self-balancing, self-running and self-processing smart energy system integrating source, network and load.
2) Promote the collaborative interaction of source, network, load and storage, and develop microgrid technology (Wu and Jiang, 2019; Fan et al., 2021). With the development of artificial intelligence, big data and other technologies, users can use information technology to intelligently adjust their energy consumption characteristics to participate in the interaction of supply and demand for the power grid. Through extensive user participation and complete information support, microgrid can promote more effective supply and demand interaction, thereby breaking the operation limit of traditional power system "power output follow with load."
3) Establish scientific and reasonable electricity price mechanism and economic policy (Davison et al., 2002; de Menezes et al., 2016). Deepen the reform of the electricity market, guide and regulate the production and consumption of electricity in the market through electricity prices, and encourage users to conduct electricity spot transactions through supply and demand interaction, electricity sales through partition walls, etc., to form a prosperous electricity market, stimulate economic vitality, and promote the sustainable and efficient development of the power system.

It can be seen that the construction of the new power system conforms to the development trend of the new generation of energy technology in the world, and is also the demand for the development of international power science and technology. In order to build and maintain a new type of power system with a high proportion of renewable energy, there will be a continuous strong demand for relevant professionals, and power grid companies will need to recruit a large number of people with knowledge in electrical, information, control, computer, business management and other fields. The professionals trained by any of the existing traditional disciplines do not have such a comprehensive knowledge base (Zhu et al., 2020). Therefore, it is urgent to develop the training concept and training path of the electrical engineering major, break the existing disciplinary boundaries, strengthen the interdisciplinary, and establish a new professional personnel training scheme and training model to cultivate professionals with low-carbon, environmental protection, innovation, and open value concepts as well as a broad basic knowledge of complex subjects and the ability to solve interdisciplinary problems.

Based on the exploration and practice of undergraduate teaching in the electrical engineering and automation major of Changsha University of Science and Technology in the past 5 years, this paper systematically expounds some thoughts, understandings and practices of the authors on the training of new generation power system professionals based on the electrical engineering discipline. The second chapter takes Changsha University of Science and Technology as an example to introduce the current educational scheme of electrical engineering undergraduate teaching; The third chapter analyzes the knowledge structure that undergraduate graduates should have to meet the needs of building new generation power systems from the perspective of industry development needs, and points out the shortcomings of using the existing electrical engineering knowledge structure to deal with the development of new generation power systems. The fourth chapter puts forward the reform plan of electrical engineering undergraduate education from two aspects of teaching scheme reform and industry-university-research linkage. Finally a conclusion.

2 THE CURRENT UNDERGRADUATE TEACHING SCHEME OF ELECTRICAL ENGINEERING——TAKING CHANGSHA UNIVERSITY OF SCIENCE AND TECHNOLOGY AS AN EXAMPLE

2.1 Introduction to Electrical Engineering Major of Changsha University of Science and Technology

Changsha University of Science and Technology is a multi-disciplinary university focusing on engineering, with coordinated development of engineering, management, management, economics, literature, and law, with undergraduate education as the main body, with post-doctoral research stations and the right to confer doctoral degrees. It is a national university of "Basic Capacity Building Project of Universities in the Central and Western Regions of China." One of the predecessors of Changsha University of Science and Technology was Changsha Electric Power College, which was founded in 1957 and was directly affiliated to the Ministry of Electric Power Industry of the People's Republic of China. Therefore, the electrical engineering major of Changsha University of Science and Technology is the main major and advantageous major of the school, which has remarkable characteristics of the power industry, and has a history of running education for more than 60 years. Now it is a national characteristic major and has been selected into the "Excellent Engineer Education and Training Program" of the Ministry of Education of China.

2.2 Professional Training Goals

The personnel training objectives of the electrical engineering major of Changsha University of Science and Technology are:

This major cultivates Senior engineering and technical personnel engaged in system operation, engineering design, manufacturing, research and development and engineering management in power systems, electrical equipment manufacturing and scientific research institutes with a sense of social responsibility, good professional ethics and comprehensive quality, strong adaptability and innovative awareness, a knowledge structure combining strong and weak electricity, a forward-looking professional vision, and engineering practice ability, self-learning ability and innovation ability. Therefore, according to the training objectives, the graduation requirements for the quality of personnel training are formulated, including 12 aspects–professional norms, engineering knowledge, problem analysis, design/development solutions, research, use of modern tools, engineering and society, environment and sustainable development, individuals and teams, communication, project management, lifelong learning:

1) Professional norms: establish a scientific worldview, have humanities and social science literacy, be able to understand and abide by engineering professional ethics and norms in electrical engineering practice, and fulfill responsibilities.
2) Engineering Knowledge: Ability to apply mathematics, natural sciences, engineering fundamentals and expertise to solve complex electrical engineering problems.
3) Problem Analysis: Be able to apply fundamental principles of mathematics, natural sciences, and engineering sciences, and through literature research, to identify, express, and analyze complex electrical engineering problems to obtain valid conclusions.
4) Design/Develop Solutions: Be able to design solutions to complex electrical engineering problems, design electrical systems, units (components) or control devices to meet specific needs, and be able to reflect innovation in the design process, taking into account social, health, safety, Legal, cultural and environmental factors.
5) Research: Be able to conduct research on complex electrical engineering problems based on scientific principles and using scientific methods, including designing experiments, analyzing and interpreting data,

and obtaining reasonable and effective conclusions through information synthesis.
6) Use of modern tools: The ability to develop, select and use appropriate techniques, resources, modern engineering tools and information technology tools for complex electrical engineering problems in order to predict and simulate complex electrical engineering problems and understand their limitations.
7) Engineering and Society: Be able to conduct rational analysis based on engineering-related background knowledge, evaluate the impact of professional electrical engineering practice and solutions to complex electrical engineering problems on society, health, safety, law and culture, and understand responsibilities.
8) Environment and Sustainability: Be able to understand and evaluate the impact of practices addressing complex electrical engineering issues on environmental and social sustainability.
9) Individuals and Teams: Ability to work as a team and function in a multidisciplinary context, taking on the roles of individuals, team members and leaders.
10) Communication: Be able to effectively communicate and communicate with industry peers and the public on complex electrical engineering issues, including writing reports and design manuscripts, making presentations, expressing clearly or responding to instructions, etc. And have a certain international perspective, able to communicate, exchange and cooperate in a cross-cultural context.
11) Project management: understand and master the basic knowledge of engineering management principles and economic decision-making methods, and be able to apply them to engineering practice in a multidisciplinary environment.
12) Lifelong learning: have the awareness of independent learning and lifelong learning, and have the ability to continuously learn and adapt to development.

2.3 Professional Curriculum System

According to the normative guidance on the training objectives and knowledge structure of electrical engineering students in the 2012 Chinese Ministry of Education's "General Colleges and Universities Subject Catalog and Major Introduction (2012)," Through the visits and seminars of employers, alumni symposiums, and fresh graduates symposiums, etc., the training objectives and graduation requirements are determined in combination with social needs, and then the knowledge, ability requirements and training methods are determined according to the graduation requirements, and finally the curriculum system is set up and formed.

2.3.1 Mathematics and Natural Science Courses

In terms of the setting of mathematics and natural science courses, the principle of combining advanced mathematics and engineering mathematics is comprehensively considered, and in conjunction with the establishment of the follow-up engineering basic courses, professional basic courses and professional courses of this major, the mathematics courses are opened: 1) Basic Advanced Mathematics: Advanced Mathematics, Linear Algebra, Probability Theory and Mathematical Statistics; 2) Engineering Mathematics: Complex Variable Function and Integral Transformation. In terms of natural science courses, combined with the graduation requirements of this major and the needs of practical engineering, the university physics course and supporting experimental courses have been opened.

The credits of mathematics courses are set at 18.5 credits, and the credits of natural science courses are set at 7 credits, all of which are required courses, accounting for 15.2% of the total credits. The compulsory courses of mathematics and natural science courses are organized by the school's Academic Affairs Office to organize professional teachers from relevant colleges to teach, and unified examinations at the end of the semester to establish unified assessment standards to ensure the teaching quality of mathematics and natural science courses and meet the graduation requirements The curriculum setting of mathematics and natural science courses is shown in **Table 1**.

2.3.2 Engineering Basic Courses, Professional Basic Courses and Professional Core Courses

In the training plan, the engineering basic courses are 24 credits, the professional basic courses are 17 credits, the professional core courses are 24 credits, and the three types of courses are 65 credits in total, accounting for 38.7% of the total credits. Engineering basic courses include "Engineering Drawing," "Circuit Theory," "Analog Electronic Technology," "Digital Electronic Technology," "Electromagnetic Field," "Computer and Programming Fundamentals" and other courses. Professional basic courses include "Electrical Machinery," "Power Electronics" Technology," "Steady-State Analysis of Power System" and other core compulsory courses, professional core courses set up "Power Plant Electrical Part," "Power System Transient Analysis," "Relay Protection Principle," "High Voltage Technology" according to the characteristics of running a school and other professional core courses and professional elective courses closely related to power system. The setting of each course is shown in **Table 2**.

2.3.3 Engineering Practice and Graduation Design

In order to cultivate professional talents with solid theoretical foundation, outstanding practical ability, strong innovation consciousness and ability, the content of practical teaching has been greatly strengthened in recent years, and the coordination and integration of curriculum teaching and practical teaching has been promoted. The teaching concept of continuously strengthening practical teaching during the 4-year study, thereby driving students' practical ability and practical ability to be greatly improved.

The practical teaching system includes three parts: Course design, internship and graduation design.

2.3.3.1 Course Design

The course design of this major is arranged to start in the same semester or the next semester after the end of the theoretical course, so that students have sufficient time and energy to

TABLE 1 | Curriculum setting of mathematics and natural science courses.

Course title	Category	Credit	Hours	Academic year
Advanced Mathematics (I)	Required	5	80	1 (Autumn)
University Physics (I)	Required	3	48	1 (spring)
Linear Algebra	Required	2	32	1 (spring)
Complex function and integral transformation	Required	3	48	1 (spring)
Advanced Mathematics (II)	Required	6	96	1 (spring)
University Physics (II)	Required	3	48	2 (Autumn)
University Physics Experiment	Required	1	30	2 (Autumn)
Probability Theory and Mathematical Statistics	Required	2.5	40	2 (Autumn)

TABLE 2 | Curriculum Setting of Engineering basic courses, professional basic courses and professional core courses.

Engineering fundamentals courses				
Course title	**Category**	**Credit**	**Hours**	**Academic year**
Computer and Programming Fundamentals	Required	2.5	40	1 (Autumn)
Introduction to Electrical Engineering	Elective	0.5	8	1 (Autumn)
Engineering Drawing	Required	2	32	1 (Autumn)
Fundamentals of programming applications	Required	2	32	1 (spring)
Circuit theory (I)	Required	3	48	1 (spring)
Circuit theory (II)	Required	3.5	56	2 (Autumn)
Electromagnetic Field	Required	2	32	2 (Autumn)
Simulation software and its application	Elective	2.5	40	2 (Spring)
Analog Electronic Technology	Required	3	48	2 (Spring)
Digital Electronic Technology	Required	3	48	2 (Spring)
Total Engineering Fundamentals	Compulsory 21 credits, elective 3 credits			
Professional Basic Courses				
Course Title	Category	Credit	Hours	Academic year
Electrical Machinery (I)	Required	3.5	56	2 (Autumn)
Electrical Machinery (II)	Required	3	48	2 (Spring)
Automatic Control Theory	Required	3.5	56	3 (Autumn)
Principle and Application of Microcomputer	Required	3	48	3 (Autumn)
Power Electronics Technology	Required	2	32	3 (Autumn)
Steady-state Analysis of Power System	Required	3.5	56	3 (Autumn)
Total professional basis	Compulsory 18.5 credits			
Professional Core Courses				
Course Title	Category	Credit	Hours	Academic year
Electrical Part of Power Plant	Required	3.5	56	3 (spring)
Transient Analysis of Power System	Required	3.5	56	3 (spring)
Relay Protection Principle	Required	4	64	3 (spring)
High Voltage Technology	Required	3	48	3 (spring)
Automatic Control Technology of Power System	Required	3	48	3 (spring)
Microcomputer protection	Elective	2	32	4 (Autumn)
Emerging Technologies of Electrical Engineering	Elective	2	32	4 (Autumn)
Relay Protection of Large Generator and Transformer	Elective	2	32	4 (Autumn)
Automatic Scheduling of Power System	Elective	2	32	4 (Autumn)
Power System Planning	Elective	2	32	4 (Autumn)
Total professional cores	Compulsory 17 credits			

complete the relevant content. The course design that each student must complete before graduation includes the course design of power grid, the course design of power plant and the course design of relay protection. The three compulsory course design links all require students to work as a team of about 4–6 people to complete the prescribed tasks through teamwork around a selected topic. Please refer to **Table 3** for relevant course information.

2.3.3.2 Internship

Arrange students to visit and learn about power plants, substations and electrical equipment manufacturing enterprises, and experience the production processes of power plants and substations, such as operation, maintenance, scheduling, and overhaul, at close range. Visit and understand the production process and production process of transformers, relay protection devices and other equipment, and complete the

TABLE 3 | Course design list.

Course design name	Design content and design requirements	Credit
Course Design—Power Grid	Main content 1. Determine the power supply voltage level. According to the size of the power supply load, the transmission distance and the existing voltage level of the power grid, the power supply voltage level is determined 2. Preliminarily formulate a number of power grid wiring schemes to be selected. According to the distribution of power points and load points, and the requirements for power supply reliability, a number of power grid wiring schemes to be selected are initially drawn up 3. Selection of main transformers in power plants and substations. The main transformers of power plants and substations are determined according to the capacity, wiring method, and role and status of power plants and substations in the power grid 4. Technical and economic comparison of power flow calculation and power grid wiring scheme. Carry out power flow calculation for the proposed power grid wiring scheme, and make technical and economic comparisons 5. Selection of conductor cross section of transmission line. For newly-built transmission lines, use the economical current density method to select the conductor cross-section 6. Voltage regulation calculation. According to the voltage regulation requirements, select and check the main transformer taps of power plants and substations Time required to complete: in 3 weeks	3
Course Design—Electrical Part of Power Plant	Main content 1. Learn the basic method and basic process of electrical primary system design in power plants, and master the general rules of electrical primary system design in power plants and substations 2. Training of basic skills of electrical primary system design: such as calculation, drawing, consulting materials and manuals, using standards and specifications, and training in computer-aided design and drawing 3. Be able to formulate and analyze the design scheme based on the function and work flow requirements of the electrical primary system of the power plant and substation, reasonably select the main wiring and the electrical wiring form used in the plant, and correctly configure the main electrical equipment 4. Be able to analyze and calculate the load and long-term heat generation according to the normal working conditions of the electrical primary system of the power plant and substation, reasonably select the number, capacity and type of transformers, and preliminarily select the main rated electrical parameters and dimensions of other major electrical equipment 5. Analyze and calculate the short-circuit current, short-term heat generation and electric power according to the short-circuit working conditions of the electrical primary system of the power plant and substation, check the short-circuit operation capability of the primary electrical equipment, and determine the electrical parameters and dimensions of the electrical equipment 6. Be able to draw electrical system diagrams, the drawings conform to the drawing standards, the dimensions and symbols are correctly marked, and the technical requirements are complete and reasonable Time required to complete: in 3 weeks	3
Course Design—Power System Relay Protection	Main content Protection configuration and setting calculation design of electrical equipment in power plants (type 1 topic) 1. Calculation of short-circuit current of a typical power network (it is recommended to use a short-circuit current calculation program to calculate) 2. Relay protection configuration scheme for electrical equipment in typical power plants or substations 3. Setting calculation of electrical equipment relay protection (can be respectively for transmission lines, transformers and other electrical equipment) 4. Design of electrical secondary circuit and selection of secondary equipment Circuit Design and Simulation of Complete Protection Devices (Type 2 topic) 1. Functional design of integrated circuit protection devices for typical electrical equipment (such as line distance protection, transformer differential protection) 2. Internal circuit design of integrated circuit protection device 3. Simulation analysis and parameter determination of the internal circuit of the integrated circuit protection device 4. Action test and simulation of integrated circuit protection device Time required to complete: in 3 weeks	3

course tasks of production practice. Each student should participate in the cognition internship and graduation internship, which content and requirements are shown in **Table 4**.

For a long time, this major has cooperated with Datang Xiangtan Power Generation Company, Datang Huayin Power Leiyang Power Plant, Hunan Ziguang Measurement and Control Co., Ltd., Huazi Technology Co., Ltd., State Grid Hunan Electric Power Company Maintenance Company Xingsha Training Branch, Hunan Dewopu Electric Co., Ltd. and other companies jointly build a practical education base, which provides a good platform for students' practical activities. In addition, students can also choose a suitable electric power company or electric company as their

TABLE 4 | The cognition internship and graduation internship.

Category	Content requirements and teaching methods	Credit
Cognition Internship	Main content 1. Understand the main equipment and production management of the internship site unit and its status in the power system 2. Carefully study and be familiar with on-site safety technical regulations and pass the safety examination 3. Understand the power plant equipment and production process, and establish the initial concept of power production 4. Further understanding of the power production process and main equipment of the power plant (for thermal power plants, understand the combustion system, soda-water system and electrical system of the power plant; for hydropower plants, learn about the hydraulic structure, water machine system and electrical system of the power plant) Internship duration: 2 weeks	2
Graduation Internship	Main content 1. Understand the work characteristics and work nature of the power production site 2. Familiar with the primary electrical wiring of the power plant (or substation), the wiring of the factory electricity (station electricity) and the corresponding operating characteristics 3. Master the configuration, working principle, setting principle, debugging method and debugging process of electrical secondary equipment such as power system relay protection and automatic device 4. Understand the characteristics and operation of new technologies and new equipment at the power production site 5. Understand on-site technical management and production command system and related issues of safe and economical operation Internship duration: 4 weeks	4

practice base according to their own situation. These bases are important places for student employment and school-enterprise industry-university-research cooperation.

3.3.3.3 Graduation Project

The graduation project (thesis) is divided into basic research papers and engineering practical papers according to the content. Basic research papers are for in-depth systematic analysis and discussion of one or some specific problems and phenomena to obtain meaningful conclusions or algorithms; engineering practical papers are based on industrial or engineering practical problems to solve the system design of practical engineering and some practical problems in engineering practice.

The undergraduate graduation project (thesis) of the electrical engineering major makes full use of the actual industrial engineering projects undertaken and participated by the teachers of this major to realize “one student, one project,” so that senior students can directly contact the practical problems in the engineering field of this major. More than 70% of the graduation project (thesis) are practical engineering design problems, which can enable students to truly feel the practical application of the knowledge they have learned. In the process of completing the graduation project (thesis), train students to master design standards and specifications, face practical engineering problems, and comprehensively use the knowledge to improve their ability to analyze and solve problems.

2.3.4 The Support Relationship of the Training Scheme to the Graduation Requirements

The contents of various courses and their assessment methods included in the professional training plan can effectively support the achievement of graduation requirements, which are: 1) professional norms (PN), 2) engineering knowledge (EK), 3) problem analysis (PA), 4) design/development solutions (DS), 5) research (RE), 6) use of modern tools (UT), 7) engineering and society (ES), 8) environment and sustainable development (ED), 9) individuals and teams (IT), 10) communication (CM), 11) project management (PM), 12) lifelong learning (LL) respectively. The correspondence matrix between the curriculum system and graduation requirements of this major is shown in **Table 5**. The degree of correlation between courses and graduation requirements is represented by “H (high),” “M (medium),” “L (low),” and H represents the course covers at least 80% of the graduation requirements, M means that the course covers at least 50% of the graduation requirements, and L means that the course covers at least 30% of the graduation requirements.

3 NEW REQUIREMENTS OF NEW GENERATION POWER SYSTEM FOR ELECTRICAL ENGINEERING STUDENTS’ KNOWLEDGE STRUCTURE

3.1 Demand for New Technology Fusion of Cyber-Physical Systems With Advanced Information Technology as the Core

The new power system will present the characteristics of deep integration of digital information and the physical system of the power grid. Using advanced information and control technology, the traditional power system can be transformed and upgraded. Using information technology in power system planning and design, scheduling optimization, safety and stability, protection and control, etc., can achieve “comprehensive, accurate measurable and highly controllable” on the power generation side; on the power grid side, a cloud-edge fusion control system can be formed; Effectively aggregate massive adjustable resources on the

TABLE 5 | Correspondence matrix of courses and graduation requirements.

Course title	Graduation requirements											
	1 PN	2 EK	3 PA	4 DS	5 RE	6 UT	7 ES	8 ED	9 IT	10 CM	11 PM	12 LL
University English										H		
Advanced Mathematics		M	H									
Engineering Drawing	H	H	M	H		H						
Linear Algebra		M	H									
Ideological and Moral Cultivation and Legal Basis	H			L			L					
Fundamentals of Computer and Programming						H						
Introduction to Electrical Engineering	H					L	L			L		
Complex function and integral transformation		M	H									
University Physics		M	H		H							
Circuit Theory		H	H	M	M							H
Outline of Modern Chinese History	H											
Electromagnetic Field			H	L			M					
Electrical Machinery		H	H	L			L	H				
Probability Theory and Mathematical Statistics		M	H		H							
Analog Electronic Technology			H	M								
Digital Electronic Technology			H	M								
Simulation software and its application		M				H						
Thermal part of power plant		H		L		L	M	L				
Steady-state Analysis of Power System			H	M	M							
Automatic Control Theory			M	H	M							
Principle and Application of Microcomputer				H		M						
Cognition Internship				M	L			M	H	M		M
Course Design—Power Grid	H	H	L	H	H	L		H	H	H	H	H
Power Electronics Technology			H	M	M					H		
Electrical Part of Power Plant		M	H	H	L			L				
Transient Analysis of Power System			H	H	M							
Relay Protection Principle			M	H	M							
High Voltage Technology			L	H	H		H	H				
Automatic Control Technology of Power System			H	M								
Course Design—Electrical Part of Power Plant	H	H	H	H	H	H		H	H	H	H	H
Course Design—Power System Relay Protection	H	H	L	H	H	H		H	H	H	H	H
Microcomputer protection		M		L		L	L	L				
Professional English	M					L	L	L		M		L
Emerging Technologies of Electrical Engineering			H	M	M							
Relay Protection of Large Generator and Transformer			H	M	M							
Automatic Scheduling of Power System			H	M	M							
Power System Planning			H	M	M							
Graduation Internship	L	L					H	M	H	H		H
Graduation Project	L	M	H	H	H	H	H	H	L	H	H	H

power consumption side to support real-time dynamic response. Through massive information data analysis and high-performance computing technology, the power grid has super sensing ability, intelligent decision-making ability and rapid execution ability.

At present, in the State Grid Corporation of China and China Southern Power Grid Corporation, new technologies such as digital twins, big data, cloud computing, Internet of Things, and artificial intelligence have begun to be popularized and applied in the industry, but the courses taught in colleges and universities are generally based on traditional circuits—motor—power system model-based theory and control technology, lack of data-centric, data-driven, model and parameter adaptive system modeling theory and methods, Students do not know how to use digital tools to model through data. Therefore, cultivating compound professionals who can adapt to the development needs of the times and can skillfully use information tools to solve practical problems in the power system is a shortcoming that must be filled in the process of building a new generation power system.

3.2 Students Need to Understand the New Mode of Power System Operation and New Control Objects With Deep Interaction Between Source, Grid, Load and Storage

The large-scale development of renewable energy places higher requirements on the flexibility of the power system. Traditionally, the demand for flexibility of the power system comes from adjusting the power supply to balance the changes and fluctuations of the load in real time, while the output of non-water renewable energy is volatile. In the scenario of power decarbonization, the power system must face the dual volatility of the load side and the power supply side caused by flexible loads and large-scale renewable energy. On the one hand, the challenges brought by this flexibility demand will be reflected in the urgent need for more effective energy storage materials and devices. On the other hand, due to carbon reduction requirements, fossil energy cannot fully undertake the task of flexible demand response. Therefore, the traditional power system must be further developed in the direction of deep interaction between source, network, load and storage.

The flexible and sufficiently elastic microgrid operation mode will become an important operation mode in the distribution network, which puts forward higher requirements for the peak regulation, frequency regulation and voltage regulation capabilities of the microgrid with a high proportion of renewable energy generation. However, in the current teaching system of electrical engineering, the proportion of professional courses closely related to the above new objects and new models is not high, and the system is not strong. For example, knowledge of energy storage materials and devices, knowledge of wind power and other renewable energy power generation principles, knowledge of microgrid operation and control, and knowledge of demand response, these professional courses closely related to the operation and control of new power systems are generally missing.

3.3 Build a New Mechanism for mid- and Long-Term, Spot and Ancillary Services Transactions in Electricity With Market Participation

The high degree of digitalization of the new power system will accelerate the development of the power market. With the deep integration of the digital economy and the traditional power industry, the power market transactions continue to enrich, including medium and long-term power transactions, spot power transactions, and auxiliary grid service transactions. These trading mechanisms will promote the transformation of energy consumption from a single, passive, generalized utilization mode to an efficient utilization mode that integrates multiple needs, active participation, and customization.

On 28 January 2022, China's National Development and Reform Commission and China's National Energy Administration issued the "Guiding Opinions on Accelerating the Construction of a National Unified Electricity Market System," which repeatedly emphasized the requirements for nearby consumption and trading of distributed energy: Encourage renewable energy power projects to supply power to nearby industrial parks or enterprises through innovative power transmission and operation methods; Promote the market-oriented transaction of distributed power generation, and support distributed power generation (including electric energy storage, electric vehicles and ships, etc.) and electricity users in the same distribution network to conduct transactions nearby through the power trading platform; In rural areas support the development of renewable energy electricity trading nearby. At present, the Guangdong electric power spot market and the regional frequency regulation auxiliary service market have carried out the settlement trial operation. The above business model is not available in the existing electricity market. Therefore, it is urgent to strengthen the economic literacy of students, so that students can understand the important role of market tools in the operation of the power system and be able to innovate the power trading mechanism.

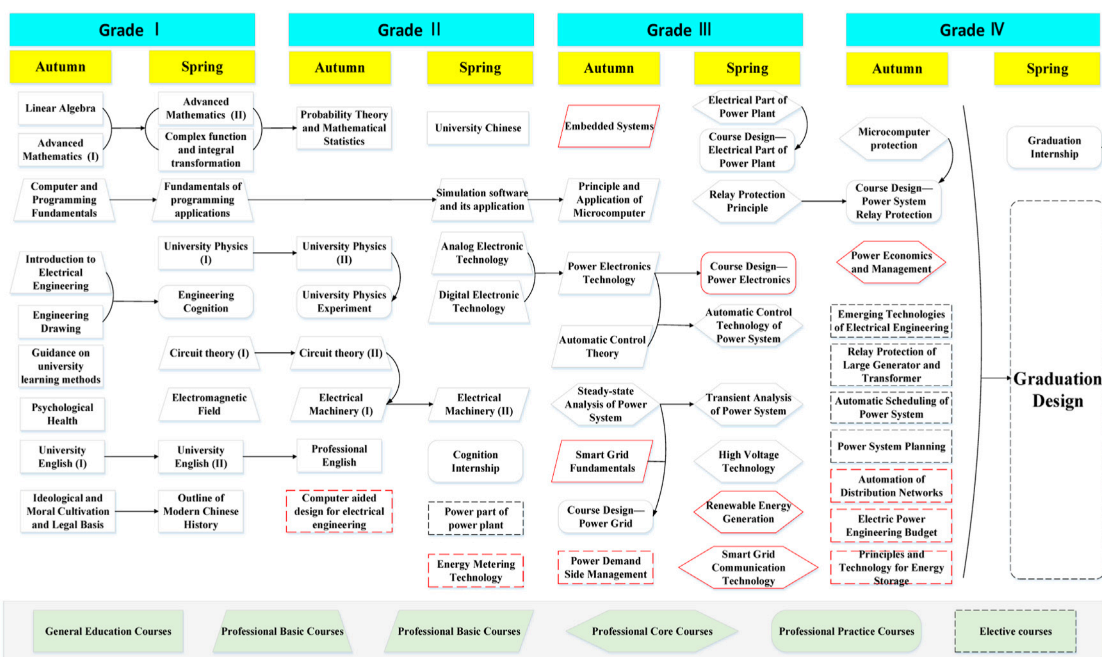

FIGURE 1 | The overall curriculum system for concentration in Smart grid Information Engineering.

4 EXPLORATION ON THE REFORM OF ELECTRICAL ENGINEERING UNDERGRADUATES TEACHING SCHEME TO MEET THE NEEDS OF NEW POWER SYSTEM CONSTRUCTION

4.1 Build a New Professional Concentration and Corresponding Training Scheme

In order to cultivate specialized talents with good basic theoretical knowledge of electrical engineering and information engineering and strong engineering practice ability to meet the needs of new power system construction and economic and social development, after long-term thinking, the authors have made in-depth adjustments to the training scheme of electrical engineering major. On this basis, a new training scheme was formulated, and a new professional concentration was developed accordingly–Concentration in Smart grid Information Engineering.

The curriculum of concentration in Smart grid Information Engineering integrates the relevant courses of "electrical engineering" and "electronic information engineering." Specialized courses are set up such as "Demand side management of power grid," "Energy Metering technology," "Automation of distribution networks," "Renewable energy generation," "Smart grid communication technology," "Power economics and management," etc., so that students not only master the production and operation rules of traditional power systems but also familiar with the development trends of smart grid as well as knowledge of technics, ethics, regulations and industry standards related to distributed power generation, microgrid control and smart grid information engineering. The overall curriculum system of the concentration in Smart grid Information Engineering is shown in **Figure 1**.

The curriculum system shown in **Figure 1** well responds to the new requirements for students' knowledge and ability proposed in **Section 3**. As for "demand for new technology fusion of cyber-physical systems with advanced information technology," through the course "Smart Grid Fundamentals," students can develop a conceptual and macro understanding of cyber-physical system of power grid; Through the course "Smart Grid Communication Technology," students are trained to understand and master various wired and wireless communication modes and principles widely used in Smart Grid; Through the course "Energy Metering Technology," students are trained to master the means of advanced metering infrastructure and understand the use of which in management of loads and distributed renewables. As for "demand for understand the new mode of power system operation and new control objects with deep interaction between source, grid, load and storage," through the course "Renewable Energy Generation," students are trained to understand the principle of renewable energy generation; Through the course "Principle and Technology for Energy Storage," students are trained to understand the application prospect and development trend of energy storage technology in power system; Through the course "Power Demand Side Management," students are introduced to the role of electric vehicles, flexible loads and other controllable loads in the regulation of Power system; Through the course "Automation of Distribution Networks," we discussed with students the principle and method of automatic control of distribution network with a large amount of distributed power generations and controllable loads. As for "demand for new mechanism for transactions in electricity with market participation," through the course "Power Economics and Management," students are trained to understand the concept of electricity market and Electric spot trading, and through the course "Electric Power Engineering Budget," students are trained to understand the concept of project cost and project budget.

Compared with the curriculum system introduced in the second part, the curriculum system highlights the characteristics of the combination of strong and weak electricity and the intersection of disciplines, and offers the following characteristic courses:

- "Smart Grid Communication Technology." Based on communication systems and principles and information communication technology, this course systematically introduces the key technologies of smart grid communication and the current situation and development of China's power communication network, including information coupling technology, cloud computing, information security and other smart grid information technologies, power communication Network system and traditional power business and new business of smart grid, new generation power communication technology and key technology of power backbone transmission network in the era of 5G and Internet of Things, intelligent power distribution communication technology and application, power data network structure and related technologies, Internet of Things Technology and research and application in smart grid, etc.
- "Automation of Distribution Networks." This course introduces the basic concepts of distribution network automation, distribution network primary equipment, distribution network automation data communication, distribution network feeder monitoring terminal, power user power information collection terminal, distribution network feeder automation, power user power consumption information Acquisition system, distribution network automation master station system, distribution network advanced application software, build the knowledge structure necessary for electrical engineering automation students, and lay the necessary foundation for engineering practical application and subsequent theoretical research.
- "Energy Metering Technology." This course includes overview of electric energy measurement technology, inductive electric energy meter, electronic electric energy meter and special electric energy meter, measuring transformer, electric energy measurement method, wiring inspection of electric energy measurement device, electric

energy measurement inspection device and inspection method, smart electric meter, automation Meter reading, remote meter reading technology, etc., enable students to have the theoretical knowledge and practical operation skills of conventional electric energy measurement technology necessary for power system and automation majors.

- "Renewable Energy Generation." This course introduces the working principles and characteristics of wind, solar, hydro, ocean, biomass, geothermal and other power generation forms, as well as power conversion technology in renewable energy power generation.
- "Principles and Technology for Energy Storage." This course introduces the basic knowledge, basic processes and some application examples of energy storage principles and technologies. Including the development history, working principle, characteristics, classification, materials, design and manufacture, testing technology, safety, etc., of energy storage batteries. At the same time, the pumped storage technology, superconducting energy storage technology, compressed air energy storage technology, metal-air battery, supercapacitor, etc., are briefly introduced.
- "Power Demand Side Management." This course introduces the importance, basic knowledge and development of DSM at home and abroad, and introduces the cost-effectiveness of orderly electricity consumption, energy-saving services, energy substitution, multi-coordinated control of source, network, and load, demand-side response, and demand-side management., demand side management under the smart grid mode and other practical technologies for power demand side management.
- "Power Economics and Management". This course includes time value of capital and equivalent calculation, basic data of power technical and economic evaluation, economic evaluation methods (deterministic evaluation method and uncertainty evaluation method), feasibility study of power construction projects, equipment renewal and leasing decision-making, etc., so that students can analyze, evaluate and make decisions on power technology and economic issues from the aspects of power technology advancement, power economic rationality, social justice and ecological adaptability, so as to choose projects and schemes with the best comprehensive benefits.

A large number of power electronic devices are indispensable in the new power system with new energy source as the main body. In fact, whether wind power, photovoltaic, charging piles, energy storage devices, are connected to the power grid through power electronic devices as the interface of the grid. Microgrid, which is developing rapidly at present, is also built with new energy source as the main body, and inevitably contains a large number of power electronic devices. Therefore, the power electronics course design is set up to design the corresponding power electronics circuit and controller centering on the application of renewable energies in microgrid, so as to improve students' ability to master power electronics technology Design content and requirements for power electronics course design is shown in **Table 6**.

The correspondence matrix between the new opened courses and graduation requirements of this major is shown in **Table 7**. The graduation requirements are: 1) professional norms (PN), 2) engineering knowledge (EK), 3) problem analysis (PA), 4) design/development solutions (DS), 5) research (RE), 6) use of modern tools (UT), 7) engineering and society (ES), 8) environment and sustainable development (ED), 9) individuals and teams (IT), 10) communication (CM), 11) project management (PM), 12) lifelong learning (LL), respectively.

4.2 Construct a Student Training Mechanism With Industry-University-Research Collaboration

In order to better integrate the technical achievements and business requirements of the new power system industry into the whole process of electrical engineering talent training and meet the needs of industrial development, the electrical engineering major of Changsha University of Science and Technology follows the concept of open cooperation, complementary advantages, and mutual benefit and win-win results, carried out school-enterprise collaborative education, through customized practical courses, compiling a series of practical teaching materials, revising practical teaching plans, adding engineering practice content on the basis of the original professional practice, incorporating social practice into the scope of professional practice, and implementing school-enterprise joint management; Professional teachers, corporate mentors, and counselors" are jointly responsible for professional guidance, job guidance and psychological counseling.

For a long time, Changsha University of Science and Technology has continuously innovated the practice of industry-university-research cooperation education based on the major strategic needs of the country and the power industry, and strived to create an engineering practice platform for school-enterprise collaboration. We have built experimental teaching bases such as the National Virtual Simulation Experiment Teaching Center for "Power Production and Control," and the National Practice Teaching Demonstration Center for "Energy System and Power Engineering," and cooperated with Hunan Provincial Power Grid Corporation to build a "Power Grid Transmission and Transformation" project. "Electrical Equipment Disaster Prevention and Mitigation" State Key Laboratory Branch, cooperated with Hunan Huazi Technology Co., Ltd. to build a national engineering practice education center, and cooperated with Hunan Electric Power Maintenance Company to build a national undergraduate teaching engineering college students off-campus practice education base, relying on these engineering practice platforms to create a new model of innovative talent training that meets the development needs of new generation power systems.

TABLE 6 | New course design—Power electronics.

Course design name	Design content and design requirements	Credit
Course design—Power electronics	Main content Students choose to complete 2 of the following 8 projects 1. Three-phase thyristor rectifier DC motor reversible drive power supply. Design main circuit, control, drive, protection circuit schematic diagram, design thyristor, rectifier transformer, DC flat wave reactance and other components rated parameters, controller parameters 2. LCC-HVDC converter for HVDC transmission. Design the main circuit, control, drive, protection circuit schematic diagram of the feeder converter, receiver converter, design thyristor, converter transformer, DC flat wave reactance, DC filter and other components rated parameters, controller parametersetc. 3. Flyback DC power supply. Design the main circuit, control, drive, protection circuit schematic diagram, design MOSFET, diode, flyback transformer and other components of the rated parameters, controller parameters 4. TCR + TSC static reactive power compensation device (SVC). Design main circuit, control, drive, protection circuit schematic diagram, design thyristor, capacitance, inductance and other components rated parameters, controller parametersetc. 5. Three-phase bridge PWM rectifier. Design main circuit, control, drive, protection circuit schematic diagram, design power devices, DC capacitor, AC filter inductor (capacitor), rectifier transformer and other components of the rated parameters, controller parameters 6. Three phase photovoltaic grid-connected inverter device. Design main circuit, control, drive, protection circuit schematic diagram, design power devices, DC capacity, energy storage inductor, AC filter inductor (capacitor), grid-connected transformer and other components rated parameters, controller parametersetc. 7. Three-phase PWM energy storage converter (PCS). Design the main circuit, control, drive, protection circuit schematic diagram, design power devices, DC capacitor, AC filter inductor (capacitor), grid-connected transformer and other components rated parameters, controller parametersetc. 8. On-line uninterruptible power supply (UPS). Design rated parameters and controller parameters of power devices, DC capacitor, AC filter inductor (capacitor), grid-connected transformer, energy storage battery and other components **Time required to complete: in 3 weeks**	3

TABLE 7 | Correspondence matrix of the new opened courses.

Course title	Graduation requirements											
	1 PN	2 EK	3 PA	4 DS	5 RE	6 UT	7 ES	8 ED	9 IT	10 CM	11 PM	12 LL
Computer aided design for electrical engineering		M		**H**		H			L	L	L	
Embedded Systems			M	H	M	M						
Smart Grid Fundamentals	M	H	H		H		H	H			M	H
Smart Grid Communication Technology		H	M	M		H						
Automation of Distribution Networks		H	M	M		H	M	M			M	
Energy Metering Technology		H	M	M		H						
Renewable Energy Generation		H	H	H	M	M	H	H				
Principles and Technology for Energy Storage		H	H	H			H	H				
Power Demand Side Management		H			H	L	L	L	L			
Power Economics and Management		L				M	H	H			H	
Electric Power Engineering Budget	H	M					M	M		H	H	
Course Design—Power Electronics		H	H	H	L	H	M	M	H	H	H	H

We have constructed a five-step progressive undergraduates training model for college students of "course teaching→enterprise practice→scientific research and development→innovative application→entrepreneurship and employment, as **Figure 2** shown:

1) Course teaching stage. This stage is mainly through classroom teaching, so that students can understand and master the basic knowledge of the major. In order to meet the development needs of the industry and meet the transformation of the energy industry, we propose to reform and reconstruct the training plan for electrical engineering professionals, upgrade and update multiple courses, and increase the proportion of information technology content;
2) Enterprise practice stage. This stage mainly organizes college students to go deep into the grass-roots power enterprises to carry out professional study, independently explore solutions to the scientific and technological problems of enterprises, and conduct problem-oriented research and study;
3) Research and development stage. At this stage, professional teachers lead the student team to carry out scientific research and project cooperation. By participating in the scientific research projects of the

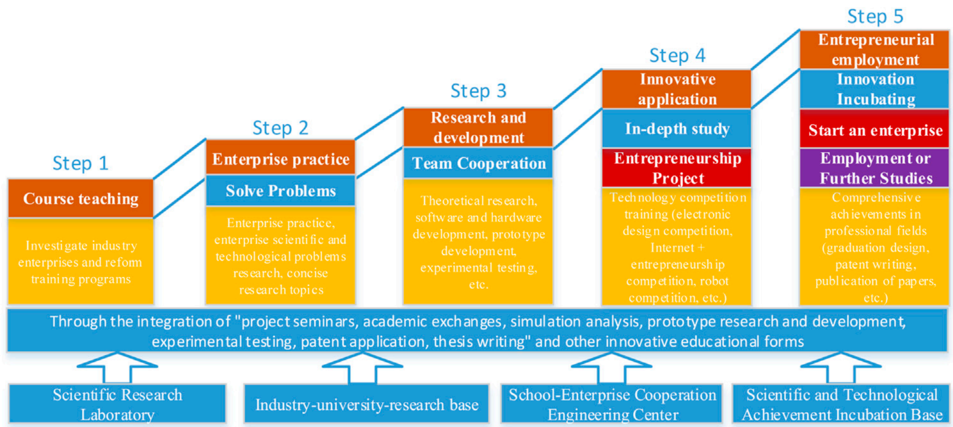

FIGURE 2 | School-enterprise collaboration five-level progressive undergraduates training model.

TABLE 8 | Calculation of grading value of graduation requirement 'EK'.

Course title	Evaluation of graduation requirement item "engineering knowledge (EK)"					
	Weight	$W_{PN,i}$	$A_{EK,i}$	$T_{EK,i}$	$A_{EK,i}/T_{EK,i}$	$G_{EK,i}$
Advanced Mathematics	M(0.5)	0.0318	10.5	15	0.7	0.02226
Engineering Drawing	H (0.7)	0.0446	22.5	30	0.75	0.03345
Linear Algebra	M(0.5)	0.0318	10.5	15	0.7	0.02226
Complex function and integral transformation	M(0.5)	0.0318	7	10	0.7	0.02226
University Physics	M(0.5)	0.0318	23	30	0.77	0.02449
Circuit Theory	H (0.7)	0.0446	22.5	30	0.75	0.03345
Electrical Machinery	H (0.7)	0.0446	28	40	0.7	0.03122
Probability Theory and Mathematical Statistics	M(0.5)	0.0318	8.8	10	0.88	0.02798
Simulation software and its application	M(0.5)	0.0318	13.5	20	0.68	0.02162
Thermal part of power plant	H (0.7)	0.0446	43.5	50	0.87	0.0388
Course Design—Power Grid	H (0.7)	0.0446	51	60	0.85	0.03791
Electrical Part of Power Plant	M(0.5)	0.0318	24.5	30	0.82	0.02608
Course Design—Electrical Part of Power Plant	H (0.7)	0.0446	43.5	60	0.73	0.03256
Course Design—Power System Relay Protection	H (0.7)	0.0446	47.5	60	0.79	0.03523
Computer aided design for electrical engineering	M(0.5)	0.0318	28	40	0.7	0.02226
Smart Grid Fundamentals	H (0.7)	0.0446	21.5	30	0.72	0.03211
Smart Grid Communication Technology	H (0.7)	0.0446	23.5	30	0.78	0.03479
Automation of Distribution Networks	H (0.7)	0.0446	15	20	0.75	0.03345
Computer aided design for electrical engineering	M(0.5)	0.0318	36	50	0.72	0.0229
Renewable Energy Generation	H (0.7)	0.0446	18.5	25	0.74	0.033
Principles and Technology for Energy Storage	H (0.7)	0.0446	19	25	0.76	0.0339
Power Demand Side Management	H (0.7)	0.0446	18	25	0.72	0.03211
Power Economics and Management	L (0.2)	0.0127	7	10	0.7	0.00889
Electric Power Engineering Budget	M(0.5)	0.0318	15	20	0.75	0.02385
Course Design—Power Electronics	H (0.7)	0.0446	44	60	0.73	0.03256
Graduation Internship	L (0.2)	0.0127	8	10	0.8	0.01016
Graduation Project	M (0.5)	0.0318	15	20	0.75	0.02385
Grading Value of Graduation Requirement G_{EK}			0.7534			

tutor, the student team conducts software and hardware development, prototype research and development, experimental testing and other scientific research work to improve their mastery of professional knowledge and temper their work ability;

4) Innovative application stage. This stage undertakes the scientific research projects or cooperative projects of the third stage of research, extracts students' innovative projects from them, and conducts relevant training for science and technology competitions under the guidance of the project team and enterprise teachers;
5) Entrepreneurial employment stage. This stage summarizes scientific research achievements, condenses dissertations, applies for patents and transforms achievements, and conducts targeted employment and entrepreneurship based on research foundations and achievements.

4.3 Build an Evaluation Mechanism to Help Improve the Quality of Education Continuously

In order to evaluate the degree of achievement of graduation requirements of this major and to test the degree of support of graduation requirements to training objectives, this paper designed the evaluation mechanism and algorithm of achievement of graduation requirements, which are described as follows.

For courses using standardized tests, The degree of course evaluation value C_{value} is calculated as follows. Where T_{value} is examination evaluation value and F_{value} is feedback evaluation value.

$$C_{value} = T_{value} \times 80\% + F_{value} \times 20\% \tag{1}$$

Where F_{value} is the weighted sum of student evaluation S_{eva} and peer evaluation P_{eva}:

$$F_{value} = (S_{eva} \times 60\% + P_{eva} \times 40\%)/100 \tag{2}$$

The examination evaluation value T_{value} is calculated as follow:

$$T_{value} = Min\left(\frac{A_{PN}}{T_{PN}}, \frac{A_{EK}}{T_{EK}}, \frac{A_{PA}}{T_{PA}}, \frac{A_{DS}}{T_{DS}}, \frac{A_{RE}}{T_{RE}}, \frac{A_{UT}}{T_{UT}}, \frac{A_{ES}}{T_{ES}}, \frac{A_{ED}}{T_{ED}}, \frac{A_{IT}}{T_{IT}}, \frac{A_{CM}}{T_{CM}}, \frac{A_{PM}}{T_{PM}}, \frac{A_{LL}}{T_{LL}}\right) \times W_1 + \frac{U_{score}}{100} \times W_2 \tag{3}$$

Where A_* are the average scores of the examination questions corresponding to each graduation requirements 1–12 shown in **Tables 5**, **7**, and T_* are the total scores of the examination questions corresponding to each graduation requirements 1–12. U_{score} is the average score of usual performance scores of students. W_1 and W_2 are the weighted value.

For the evaluation of the curriculum system, the grading value of the curriculum system G_{cum} is calculated as follows.

$$G_{cum} = Min(G_{PN}, G_{EK}, G_{PA}, G_{DS}, G_{RE}, G_{UT}, G_{ES}, G_{ED}, G_{IT}, G_{CM}, G_{PM}, G_{LL}) \tag{4}$$

Where G_* are the grading value of each graduation requirements 1–12 shown in **Tables 5**, **7**. Take G_{PN} as an example, its calculation rules are as follows.

$$G_{PN} = \sum_{i=1}^{k}\left(W_{PN,i} \times \frac{A_{PN,i}}{T_{PN,i}}\right) \tag{5}$$

Where k denotes the number of courses within sub-item professional norms (PN). $W_{PN,i}$ is the normalized course weight value for sub-item PN. According to **Tables 5**, **7**, H represents the course covers at least 80% of the graduation requirements, M means that the course covers at least 50% of the graduation requirements, and L means that the course covers at least 30% of the graduation requirements. Therefore, corresponding to graduation requirements, the initial weight of courses in each sub-item $IW_{PN,i}$ is:

$$IW_{PN,i} = \begin{cases} 0.7 & where\ PN = H \\ 0.5 & where\ PN = M \\ 0.2 & where\ PN = L \end{cases} \tag{6}$$

$$W_{PN,i} = IW_{PN,i} \Big/ \sum_{i=1}^{k} IW_{PN,i} \tag{7}$$

For G_{PN}, G_{EK}, G_{PA}, G_{DS}, G_{RE}, G_{UT}, G_{ES}, G_{ED}, G_{IT}, G_{CM}, G_{PM}, G_{LL}, the calculation is the same as for $G_{PN.}$ the grading value of the curriculum system G_{cum} curriculum. When the grading value of the curriculum system G_{cum} is obtained, observe its value. The closer its value is to 1, the more responsive it is to graduation requirements. Generally speaking, when G_{cum} is greater than 0.7, it is considered that the curriculum scheme has basically reached the training goal.

The following takes engineering knowledge (EK) as an example to calculate the degree of achievement of this item. The courses, course weights, total score of course examination involved in item EK (T_{EK}), average score of students (A_{EK}), degree of achievement of each courses for item EK (A_{EK}/T_{EK}), and the final grading value of graduation requirement 'EK' (G_{EK}) are shown in **Table 8**.

The calculation methods for the remaining 11 graduation requirements are similar and will not be described here. The minimum value of the degree value of all graduation requirements is taken as the index to evaluate the degree of the curriculum system. The closer this value is to 1, the closer the student is to the desired goal of the preset graduation requirements.

5 CONCLUSION

With the construction and development of new power systems, the existing teaching schemes and personnel training systems for electrical engineering and automation can not fully meet the talent needs of new power system construction. Therefore, it is urgent to jump out of the original framework and build a new undergraduates training scheme through the intersection of disciplines. The author introduces the current undergraduate teaching scheme of electrical engineering in Changsha University of Science and Technology, And from the perspective of industry development needs, it analyzes the knowledge structure that undergraduate graduates should have to meet the needs of building new power systems, and points out the lack of current training scheme. Based on the exploration and practice of undergraduate teaching in the electrical engineering and automation major of Changsha University of Science and Technology, the author proposes a reform plan for undergraduate education in electrical engineering that meets the needs of the construction of new power systems from three aspects: reform of the teaching scheme, educate students through industry-university-research practice, and establish an evaluation mechanism for the entire teaching process. It provides a valuable reference for relevant teaching institutions engaged in electrical engineering education.

AUTHOR CONTRIBUTIONS

WG wrote the manuscript; FD contributed to the structure and outlines of the manuscript; XW provide useful comments on the overall structure and content of the manuscript; FC helped improve the language of the manucript.

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