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Curriculum Reconstruction and Teaching Methodology Reform for "Modern Power Electronics Technology" with AI Integration

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Abstract: Against the backdrop of the "Carbon Neutrality" goal and the digital transformation of the energy sector, modern power electronics technology is rapidly evolving toward higher switching frequencies, greater integration, and enhanced intelligence. Addressing persistent challenges in traditional curricula — such as outdated knowledge structures, insufficient interdisciplinary integration, and inadequate cultivation of innovative capabilities, this study proposes a reconstruction scheme for an "AI+" modern power electronics curriculum system. Utilizing a "vertically tiered and horizontally integrated" curricular framework, artificial intelligence methodologies are systematically embedded into teaching modules encompassing device characterization, topology optimization, control strategy design, and engineering case studies. Furthermore, by leveraging project-based learning (PBL), virtual-real fused experimentation, and innovation-driven practical activities, a progressive competency development pathway is established, bridging "foundational theory, comprehensive application, and innovative practice". Teaching practice demonstrates that this pedagogical model significantly enhances students' ability to solve complex engineering problems and fosters interdisciplinary innovative thinking.

1. Introduction

Electrical energy serves as the primary energy source driving human societal development. Modern power electronics technology, acting as the critical interface among renewable energy generation, energy storage systems, and end-user terminals, lies at the heart of both new-type power systems and smart manufacturing initiatives. The course Modern Power Electronics Technology is a core professional program designed for graduate students specializing in Electrical Engineering [1]. It is characterized by its integration of strong and weak electrical systems, the synergy between system-level architectures and component-level characteristics, and an equal emphasis on theoretical foundations and practical applications. Grounded in fully-connected power devices, the curriculum utilizes key circuit topologies—including PWM rectifiers, isolated DC-DC converters, various passive inverter circuits, and AC-AC variable frequency circuits—as entry points. It places particular focus on elucidating the physical concepts of energy conversion and the essence of power flow control within these four typical converter categories. Furthermore, aligned with cutting-edge advancements in the field, the course explores current applications and existing challenges of modern power electronics across diverse domains such as energy storage, renewable energy grid integration, new energy vehicles, power transmission, and power quality control.

Driven by the rapid advancement of emerging strategic industries such as new energy and intelligent manufacturing, modern power electronic systems exhibit distinct characteristics including high dynamic response requirements, multi-objective optimization demands, and multi-time-scale coupling. These trends pose significant challenges to control complexity and design paradigms. Concurrently, artificial intelligence has demonstrated substantial potential in state perception, parameter identification, fault prediction, and control optimization, profoundly driving the paradigm shift in power electronic systems from "mechanism-driven" to "data-mechanism dual driven" approaches [2,3]. However, the current curriculum of Modern Power Electronics Technology for graduate students in electrical engineering remains structurally lagging. Firstly, the syllabus emphasizes classical circuit theory and steady-state analysis while inadequately covering frontier topics such as data-driven modelling and intelligent control strategies. Secondly, the curriculum suffers from rigid disciplinary boundaries, lacking deep interdisciplinary integration with control theory and computer science. Thirdly, practical teaching predominantly relies on confirmatory experiments, failing to cultivate students' innovative competence in solving cutting-edge engineering problems.

Consequently, this paper focuses on the deep integration of AI and power electronics, investigates the structural reform of the curriculum system and explores pedagogical models for "AI+ Power Electronics" courses, aiming to provide theoretical insights and practical paradigms for fostering graduate students' innovative capabilities.

2. Curriculum Architecture design for "AI+" *Modern Power Electronics Technology*

2.1. Vertically Stratified Five-Tier Curriculum Progression

Vertical stratification primarily involves partitioning the curriculum into five progressive tiers, facilitating a scaffolded advancement from rudimentary knowledge to sophisticated applications and, ultimately, to innovation. Crucially, AI integration touchpoints are deliberately embedded within each tier. Specifically, the vertical progression comprises the following layers: the Mathematical-Conceptual Layer, the Electrical Engineering Fundamental Layer, the AI + Professional Core Layer, the Frontier Interdisciplinary Layer, and the Comprehensive Practice Layer. The corresponding curriculum modules and AI integration strategies are illustrated in Figure 1.

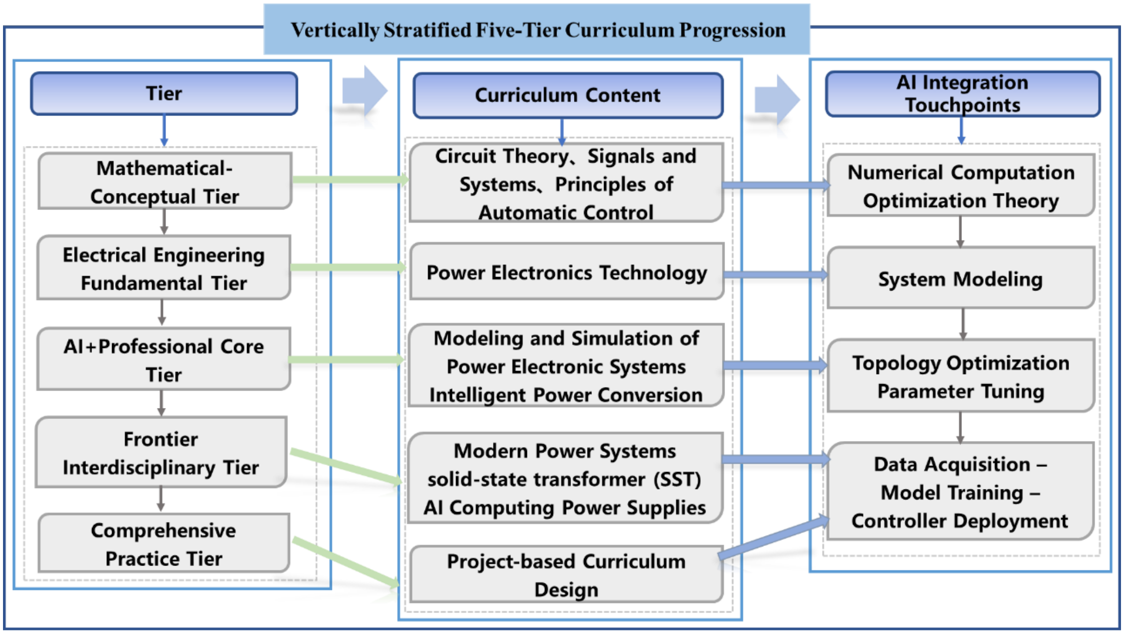

Figure 1: Architecture of the Vertically Stratified Five-Tier Curriculum Progression and Key AI Integration Touchpoints.

2.2. Horizontal Articulation via Synergistic Curriculum Modules

Horizontal articulation is pivotal for dismantling curricular silos and establishing synergistic knowledge linkages across domains. Four specific interfaces include:

(1) Device-Semiconductor Material. This module introduces “Data mining for Device Characteristics”, students can employ AI algorithms—such as recurrent neural networks—to analyse aging data and predict the remaining useful life (RUL). This bridges materials science with predictive maintenance strategies.

(2) Topology - Converter Synergy. This interface integrates computational intelligence into power electronics design. For example, multi-objective optimization of converters can be achieved using Genetic Algorithms (GAs), Machine Learning (ML), and Bayesian Optimization. The key focus is the exploration of AI-assisted automated topology generation, enabling students to move beyond manual design heuristics toward algorithmic synthesis.

(3) Modulation - Control Integration. Addressing the limitations of linear control, this module connects traditional pulse width modulation (PWM) and PID control with advanced AI paradigms. It emphasizes the application of Deep Reinforcement Learning (DRL) for model-free control and adaptive modulation strategies, allowing converters to autonomously adapt to dynamic operating conditions without precise mathematical models.

(4) System-Integration Convergence. Anchored in real-world engineering projects, this module analyzse the deployment of intelligent diagnostics and optimal control in complex systems. Students evaluate how AI-driven solutions address practical challenges in condition monitoring and fault-tolerant control, thereby solidifying the link between theoretical knowledge and industrial application.

3. Innovative Educational Initiatives

3.1. Cultivation Practical and Innovative Capabilities Through Penetrating "Research - Teaching" and "Discipline - Ideology" Integration

The crux of cultivating applied and innovative capabilities lies in honing students' "translation" proficiency—mapping real-world complexities into engineering models—and fostering systematic design thinking. Leveraging the university's "Research-Integrated Teaching" initiative, the curriculum team authentic challenges from industry-academia-research collaborations into a structured pedagogical case repository. These cases are tiered into three categories: basic cases (linking single knowledge points), comprehensive cases (integrating multiple domains to solve typical engineering problems), and open-ended cases (encouraging cognitive expansion and innovative design). This scaffolding guides students through a progressive trajectory from comprehension to application and, ultimately, to innovation. Throughout the course, instruction is anchored by these authentic, research-infused problems. Students engage in "learning by doing" as they attempt solutions, while instructors provide targeted theoretical guidance and methodological critiques, prompting students to transition into "researching by reflecting."

Parallel to the cultivation of knowledge and capabilities, the curriculum places significant emphasis on value leadership. The instructional team continuously identifies and reframes ideological and political elements inherent in the subject matter, seamlessly integrating them into the fabric of knowledge dissemination and competency development. This effort has culminated in a curated ideological case repository, effectively expanding the curriculum's breadth and depth. Consequently, value leadership is achieved through imperceptible influence rather than overt indoctrination. The implementation pathways for the dual integration of research-teaching and discipline-ideology are illustrated in Figure 2.

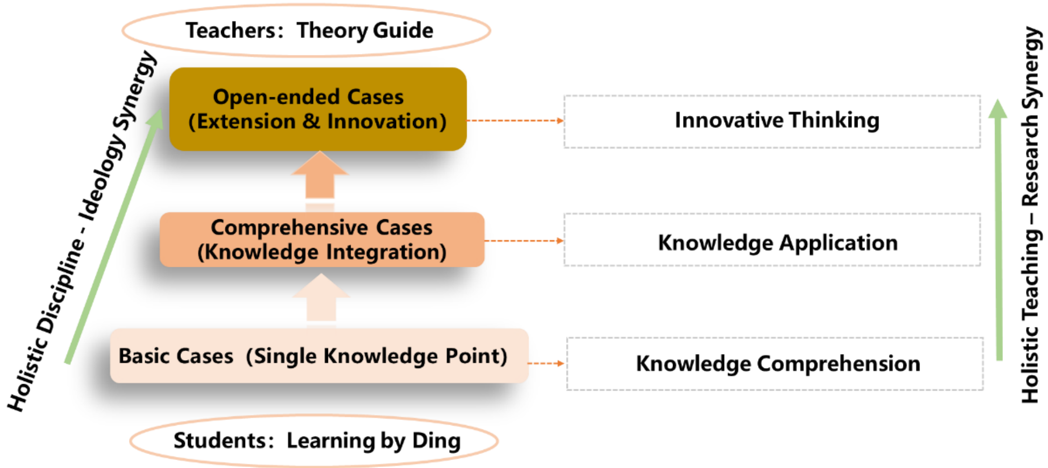

Figure 2: The Implementation Pathways for the Dual Integration of Teaching- Research and Discipline-Ideology.

3.2. A Progressive "Knowledge - Application - Innovation" Instructional Pathway

The cornerstone of implementing this three-tiered progressive pathway and its associated diversified assessment methods lies in acknowledging and accommodating the heterogeneity of students' individualized learning needs. Rather than adopting a one-size-fits-all approach, the curriculum provides multiple learning pathways and a personalized support system designed to unlock the potential of diverse learner profiles. The specific operational modalities of this progressive instructional trajectory are illustrated in Figure 3.

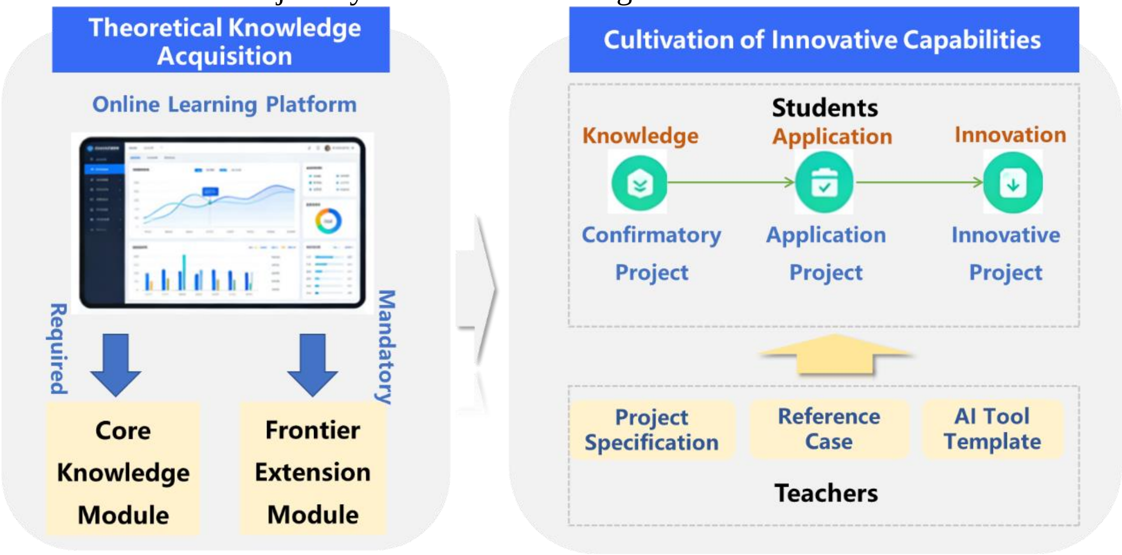

Figure 3: Implementation Path of the Three-Stage Progressive Teaching Model.

At the theoretical learning stage, the institution leverages big data from the university's online learning platform to generate personalized learning pathways and resource tiers for each student. These recommendations are informed by students' performance in prerequisite courses as well as their individual preferences. Notwithstanding this personalization, all students are required to attain mastery of the Core Knowledge Module, ensuring a shared foundational competence.

At the student level, the cultivation of application and innovation capabilities is structured around a three-tier project system: confirmatory, application-oriented, and innovative design projects. All students must complete a confirmatory project, which emphasizes the application of a single knowledge point. Subsequently, students are required to complete at least one additional project, selecting either an application-oriented project—which integrates multiple knowledge points to address typical problems—or an innovative design project, characterized by open-ended scenarios that demand solution design and evaluation.

At the teacher level, tailored instructional frameworks are provided to support projects at different levels, including project specifications, reference cases, and AI tool templates. Instructors are tasked with guiding students to engage in exploratory thinking and creative practice grounded in course content, thereby facilitating the production of individualized outcomes.

4. Construction of a Diversified Evaluation System

The course adopts a blended assessment structure comprising formative assessment (50%) and a final written examination (50%), employing diversified evaluation methods. Formative assessment encompasses regular assignments, discussions, in-class quizzes, and course projects. Regular assignments and quizzes primarily evaluate students' knowledge comprehension, while course projects are assessed based on knowledge application, the completeness of solution design, presentation effectiveness, and innovation. The final written examination is administered in accordance with the course syllabus, covering three question types—short answer, analysis, and design. Non-standard-answer questions are incorporated to primarily assess students' ability to apply knowledge. The diversified evaluation system is illustrated in Figure 4.

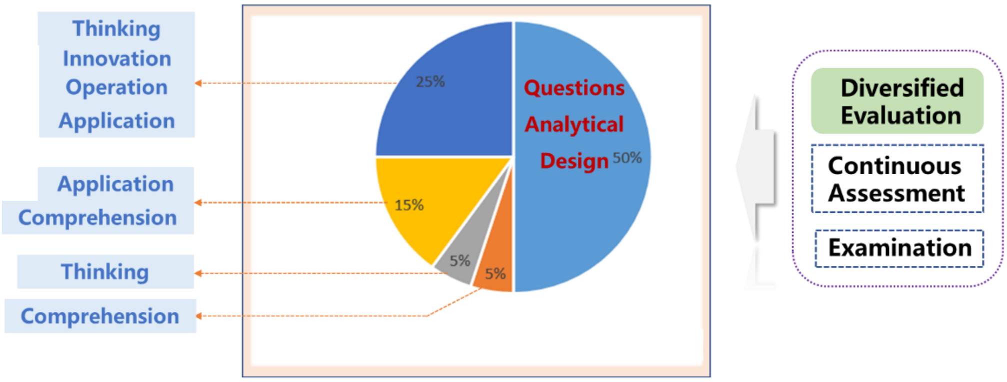

Figure 4: Construction Path of the Diversified Evaluation System.

5. Conclusions

The reconstruction of the "AI+" modern power electronics curriculum system represents an imperative response to the ongoing energy revolution and the deepening convergence of technologies. By implementing a vertically layered architecture, fostering horizontal synergy among course modules, and underpinning the system with holistic teaching–research and discipline–ideology integration, the reform effectively addresses long-standing challenges in traditional pedagogy, notably the fragmentation of disciplinary knowledge and the scarcity of innovation-driven learning. Practical evidence demonstrates that this framework enhances students' capacity to analyse physical mechanisms and apply AI methodologies to solve complex engineering problems. Consequently, it offers valuable insights and a replicable model for advancing emerging engineering education in electrical disciplines.

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