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Digital-Intelligence-Driven Teaching Reform of the Relay Protection Technology Course

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Abstract: The new power system changes protection objects, fault characteristics, and operating modes, requiring students to integrate fault analysis, protection configuration, relay setting, and field troubleshooting. Existing instruction often fragments knowledge, obscures operating mechanisms, separates theory from engineering practice, and relies on outcome-only assessment. This paper proposes a digital-intelligence-driven reform pathway for the Relay Protection Technology course. The pathway retains conventional protection principles while reorganizing objectives, content, methods, faculty collaboration, instructional support, and assessment around engineering competence. It also develops a smart classroom based on a course knowledge graph, a fault-case repository, a relay-setting task repository, and a virtual-real laboratory repository. These resources support visualization, data-based fault reasoning, setting verification, and process evaluation. The framework provides a practical route from knowledge transmission to protection-scheme design and engineering competence under Emerging Engineering Education.

1. Introduction

The Outline for Building a Leading Country in Education (2024–2035) calls for curriculum reform oriented toward the digital economy and future industries [1], while Emerging Engineering Education emphasizes adaptation to new technologies and industries [2]. Relay Protection Technology connects power-system fault analysis, secondary-system design, operation and maintenance, and safety responsibility. The new power system therefore requires more than additional software demonstrations: course objectives, practical environments, and assessment must respond to changing protection objects and engineering tasks. In this paper, digital-intelligence-driven reform means using data to connect teaching activities, digital platforms to extend engineering scenarios, and intelligent tools to support diagnosis and feedback while preserving students' understanding of protection principles. Previous work has shown the value of digital resources, blended learning, and virtual laboratories in relay-protection instruction [3]. Building on that foundation, this study develops a competence-oriented framework that links knowledge, engineering cases, experimentation, and assessment.

2. Relay Protection Technology in the Era of Digital Intelligence

2.1. New Requirements for Relay-Protection Talent in the New Power System

Large-scale integration of wind power, photovoltaic generation, energy storage, and power-electronic equipment changes source structure, network configuration, and fault behavior. Current-limiting interfaces and bidirectional power flows may alter fault-current magnitudes, phase relations, and sequence components, complicating protection configuration. National Energy Administration documents consequently emphasize new-power-system safety, renewable control and protection, risk monitoring, and early warning [4]. Course objectives must therefore extend beyond recalling operating equations or completing idealized short-circuit calculations. Students should identify complex faults, analyze protection logic, coordinate relay settings, and justify engineering decisions with data and standards.

Smart substations further transform protection information through merging units, sampled values, GOOSE messaging, intelligent terminals, and networked secondary circuits. Students must master classical overcurrent, distance, pilot, and differential protection while understanding information flows, communication abnormalities, and field-testing procedures. The course must retain theoretical depth, update engineering content, and strengthen data-analysis competence.

2.2. Digital Education and Intelligent Teaching as Trends in Engineering Education

Online courses, virtual simulation, digital laboratory devices, and learning analytics can overcome temporal, spatial, and equipment constraints. Students can observe fault quantities and protection timing, vary operating modes and relay settings, and compare outcomes; teachers can use learning data to diagnose recurring errors and provide differentiated guidance. The Artificial Intelligence + Education Action Plan also promotes deeper integration of intelligent technology with teaching [5]. Evidence from project-driven reform indicates that authentic projects can connect knowledge acquisition with practical problem solving [6].

These tools should be evaluated by their contribution to course objectives rather than platform usage. Because relay protection affects grid safety, AI-generated conclusions must be checked against principles, standards, calculations, and simulations. Students should use intelligent tools to improve analysis while remaining responsible for data provenance, model limits, and final engineering judgment.

3. Reflections on Teaching Reform under Emerging Engineering Education

3.1. Technological Change Makes Curriculum Reform Imperative

Conventional courses usually follow fault analysis, protection requirements, individual protection types, and setting calculation. This sequence supports theoretical learning but does not fully represent the engineering chain of smart substations, renewable-energy integration, and digital operation. Students may calculate a setting yet struggle to connect the primary diagram, transformer configuration, protection logic, communication information, breaker action, and fault records. Reform must retain the theoretical sequence while linking it to complete protection tasks.

Authentic relay-protection tasks begin with faults rather than textbook chapters. Students must identify fault types from disturbance records, determine protection zones, check coordination against setting sheets, and diagnose maloperation or failure to operate. These tasks require fault data, protection logic, device operation, and scheme justification to be taught within one problem-solving process. Digital-intelligence technologies provide the data and platform support needed for this integration.

3.2. Problems in the Conventional Teaching Model

First, relationships among fault characteristics, protection criteria, setting principles, delays, and zones are often implicit, so students treat equations as isolated results. Second, short-duration protection processes are difficult to visualize with conventional blackboard instruction, making it hard to connect electrical quantities, measurement trajectories, logic decisions, and breaker actions.

Third, theory and engineering practice remain weakly connected. Textbook examples use idealized faults, whereas field disturbances include transition resistance, measurement error, communication abnormalities, and changing component states. The shortage of authentic records, grid topologies, and device applications limits students' ability to analyze waveforms, calculate settings, and understand secondary systems [7]. Laboratory constraints also leave little room to design scenarios or investigate unexpected results.

Finally, summative examinations mainly measure concepts and calculations. They provide limited evidence of students' ability to interpret records, configure protection, operate devices, explain behavior, and solve engineering problems collaboratively. Without continuous learning evidence, teachers cannot identify whether difficulties arise from calculation, principle comprehension, setting coordination, or laboratory operation.

3.3. Digital Intelligence as a Preferred Reform Path

As illustrated in Figure 1, transformation of the new power system creates new competence requirements and exposes the limitations of conventional teaching, thereby establishing the rationale for digital-intelligence-driven curriculum reform.

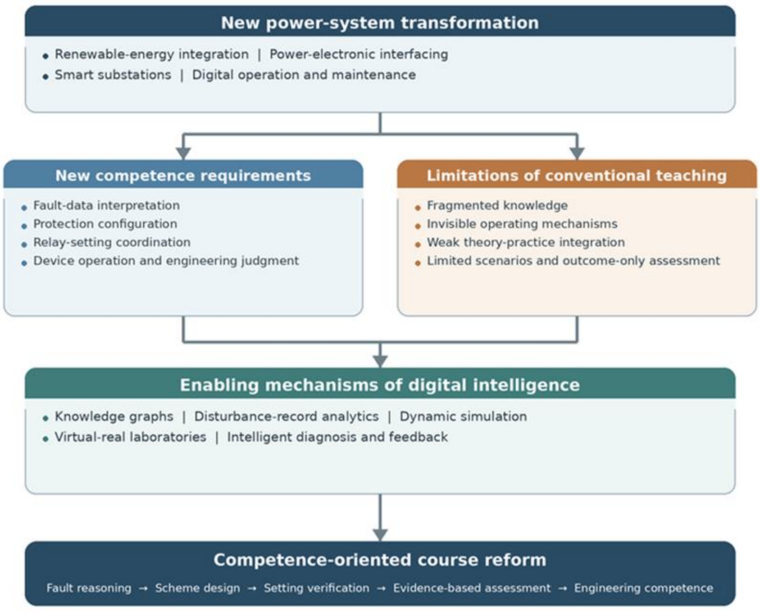

Figure 1: Rationale and logical pathway for digital-intelligence-driven reform of the Relay Protection Technology course.

Digital intelligence can connect knowledge, data, simulation, experimentation, and assessment. Knowledge graphs reveal relations between concepts and engineering objects; disturbance records and simulations visualize protection operation; virtual laboratories expand reproducible fault scenarios; and intelligent tools provide differentiated feedback. These functions turn abstract mechanisms into observable processes, fixed examples into variable scenarios, and result-only examinations into process evidence.

Digital intelligence should remain embedded in conventional relay-protection teaching rather than forming a separate technology-centered system. Digital resources and engineering data should support students' problem solving while teachers retain the theoretical sequence and verify AI-assisted conclusions. Existing curriculum-reform studies likewise call for coordinated changes to objectives, content, methods, staff, support, and management [3,6].

4. Strategies for Digital-Intelligence-Driven Teaching Reform

4.1. Strengthening Conventional Foundations Instead of Rebuilding from Scratch

Conventional and digital-intelligence-based teaching are complementary. Classroom explanation remains essential for derivation and logical discrimination, while digital tools are suited to knowledge relations, scenario reconstruction, process recording, and personalized feedback. Reform should retain fault analysis and protection principles as the main sequence and upgrade the six teaching elements summarized in Table 1.

Table 1: Comparison between Conventional and Digital-Intelligence-Driven Teaching.

Teaching element	Conventional teaching	Digital-intelligence-driven teaching
Teaching objectives	Master protection principles and basic setting methods	Develop integrated engineering competence in fault analysis, protection configuration, setting verification, data interpretation, and safety responsibility
Teaching content	Typical power grids and classical protection principles	Classical principles integrated with smart substations, renewable-energy protection, digital secondary systems, and engineering cases
Teaching methods	Classroom lectures, blackboard derivations, and verification experiments	Problem-driven learning, knowledge-graph guidance, dynamic simulation, virtual-real integrated experiments, and project collaboration
Teaching team	Independent instruction by the course teacher	Collaboration among course teachers, laboratory instructors, information-technology teachers, and enterprise engineers
Teaching support	Textbooks, courseware, and relay-protection laboratory devices	Disturbance-record repository, relay-setting task repository, virtual-simulation platform, physical devices, and teaching-data platform
Teaching assessment	Final written examination and laboratory reports	Combined assessment of knowledge, process, experiments, projects, and comprehensive application, emphasizing an evidence chain and formative evaluation

In teaching objectives, the emphasis should extend from calculation and principle recall to fault identification, protection configuration, verification, and explanation. Classical theory remains the foundation, supplemented by smart-substation information flows, renewable-energy fault characteristics, digital protection testing, and accident reviews. Foundational, application, and extension modules can then form a coherent curriculum. Similar modular reforms in electrical engineering have linked practical tasks with assessment [8].

Teaching should combine rigorous explanation with student inquiry. Teachers derive key protection characteristics, while students use simulation and data analysis to examine the effects of fault location, transition resistance, operating mode, and device parameters. Course teachers lead principles and task design; laboratory instructors manage devices and platforms; enterprise engineers contribute anonymized cases; and information-technology teachers support data governance and responsible tool use.

Instructional support should use reusable resource units. Each fault case should include a primary diagram, disturbance record, relay settings, event report, and analysis task. An evidence matrix aligned with course objectives can assess competence through calculation, simulation records, device operation, project reports, and oral defense.

4.2. Following Technological and Cognitive Trends Instead of Pursuing Digitalization Blindly

Digital-intelligence reform should target activities that are difficult to observe, reproduce, or evaluate, rather than insert AI into every lesson. The following components align technology with protection practice and students' cognitive needs.

Visualization of protection principles. Synchronized animations can connect waveforms, measurement trajectories, operating zones, logic nodes, and breaker states. In distance protection, students can vary fault location and transition resistance and observe measured impedance in the complex plane, linking equations, diagrams, and operating results.

Data-based fault analysis. A case repository should combine simulation data, anonymized disturbance records, and operation reports. Students identify fault time, type, and phase from waveforms, then infer the operation sequence from switching signals, pickup information, and the primary diagram. Cases should include correct operation, failure to operate, maloperation, and communication or measurement abnormalities.

Intelligent relay-setting calculation. Parameterized tasks can vary network structure, operating mode, and fault condition while recording calculation steps. Intelligent tools may check units, formula selection, interval constraints, and coordination, but students must verify final settings through manual calculation and simulation.

Virtual-real integration in laboratory teaching. Laboratory teaching should progress from virtual preparation and digital simulation to device operation and result review. Virtual environments support repeated practice and unsafe or rare scenarios, while physical devices preserve experience with interfaces, wiring, and signal transmission. Both should address the same task. Related microcontroller teaching shows that integrating hardware, programming, sensing, and evaluation strengthens practical skills [9].

Engineering adaptation of course content. Smart-substation information exchange, renewable-energy protection, active distribution networks, and wide-area protection can be organized as extension modules. New content should be introduced through its connection to classical principles, such as bidirectional power flow in directional elements or sampling synchronization in differential protection.

Process-oriented teaching assessment. Assessment may combine foundational knowledge (25%), learning process (15%), simulation laboratories (20%), project practice (25%), and comprehensive application (15%). Evidence should include diagnostic tasks, reasoning records, models, device operations, project products, and case defenses. Assessment data should guide teaching improvement rather than serve as mechanical surveillance.

4.3. A New Teaching Model: The 'One Graph, Three Repositories, and Four Stages' Smart Classroom

To connect digital resources with classroom teaching, this paper proposes a smart relay-protection classroom organized around 'one graph, three repositories, and four stages.' The course knowledge graph is the organizing structure; the repositories contain fault cases, relay-setting tasks, and virtual-real laboratory resources; and the stages cover pre-class diagnosis, in-class reasoning, virtual-real verification, and post-class feedback. Engineering problems provide the entry point, protection principles the main thread, and competence assessment the outcome.

The knowledge graph links grid structure, operating mode, fault type, electrical characteristics, protection criteria, setting principles, and operating results. Students can trace prerequisite knowledge and relations with adjacent protection, instrument transformers, breakers, and communication links, while teachers map tasks and common errors to knowledge nodes.

The three repositories should use unified case identifiers and data interfaces. A transmission-line fault can extend across all three: students analyze the disturbance record, calculate settings from network parameters, and verify behavior through simulation and a physical device. This continuity connects theory, calculation, and experimentation.

The four stages form a feedback loop. Before class, diagnostic tasks identify prerequisite gaps; during class, students reason from contradictory engineering evidence; in experiments, they vary fault conditions and compare predicted with observed behavior; after class, the platform summarizes knowledge-node mastery, errors, and project performance for collective review and individual guidance.

AI use requires clear boundaries. Intelligent tools may explain concepts, generate exercises, identify procedural errors, and organize reports, but they should not produce unverified relay settings or replace students' conclusions. AI-assisted results should undergo principle checking, manual recalculation, simulation verification, and source attribution; this verification should form part of assessment.

The smart classroom should also connect with enterprise practice. Grid companies and manufacturers can provide anonymized cases, representative setting sheets, and device-testing tasks, while university and enterprise instructors jointly design project-assessment criteria. Students can complete protection-scheme designs, accident reviews, and technical defenses against the same competence objectives.

5. Conclusions

The new power system requires Relay Protection Technology to address knowledge renewal, broader engineering scenarios, and competence reconstruction. Digital intelligence can make abstract mechanisms observable, reproduce complex faults, connect engineering tasks, and collect process evidence. Reform quality depends on whether these resources are organized around course objectives and verified against protection principles.

This paper proposes coordinated reform of objectives, content, methods, teaching staff, instructional support, and assessment, together with a smart classroom built on one graph, three repositories, and four stages. The framework retains classical protection theory, uses fault data and engineering tasks as organizing drivers, integrates virtual and physical practice, and requires verification of AI-assisted results. Future implementation should evaluate fault-analysis accuracy, setting accuracy, laboratory performance, and scheme-design competence through pre/post tests, control-group comparisons, project products, and student interviews.

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