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Review

A Brief Survey on the Development of Intelligent Dispatcher Training Simulators

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Abstract: The well-known dispatcher training simulator (DTS), as a good tool to train power system dispatchers, has been widely used for over 40 years. However, with the high-speed development of the smart grid, the traditional DTSs have struggled to meet the power industry's expectations. To enhance the effectiveness of dispatcher training, technical innovations in DTSs are becoming more and more demanding. Meanwhile, the ever-advancing artificial intelligence (AI) technology provides the basis for the design of intelligent DTSs. This paper systematically reviews the traditional DTS in terms of its origin, structure, and functions, as well as limitations in the context of the smart grid. Then, this paper summarizes the AI techniques commonly used in the field of power systems, such as expert systems, artificial neural networks, and the fuzzy set theory, and employs them to develop intelligent DTSs. Regarding a less studied aspect of DTSs, i.e., intelligent training control, we introduce the Adaptive Learning System (ALS) to develop a personalized training program, which will also be an important aspect of future research.

Keywords: dispatcher training simulator (DTS); dynamic simulation; intelligent training; artificial intelligence; adaptive learning; Felder-Silverman index; Adaptive Educational Hypermedia Systems

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1. Introduction

With the continuous expansion of power systems and the increasing deployment of power electronic devices, the stability of power systems becomes more complex, and the impact of blackouts becomes more serious. The power industry is facing severe challenges in terms of operational reliability and economy [1–3]. Therefore, it is necessary to improve the operating level of power grid dispatchers, such as the detection, handling, and prevention of emergencies [4]. However, due to the complex structure and high-security requirements of power systems, it is almost impossible to use real power systems to train dispatchers. For this reason, it is necessary to construct the dispatcher training simulator (DTS).

DTS is a digital simulation system for training power grid dispatchers. It builds a set of mathematical models of basic components and possible situations in the actual power system, thus simulating various dispatching operations and post-accident system conditions. It then transmits all information to a simulated model of the power system control center, providing a realistic training environment for the dispatcher trainees so as to train dispatchers efficiently without disturbing the normal operation of the actual power system [5]. It is generally considered one of the most effective anti-accident measures to improve dispatchers' operational skills through simulation training in order to prevent the emergence of dangerous operation modes of the power grid and to prevent the evolution of minor faults into major accidents [4,6,7].

The concept of DTS was first proposed by Latimer in 1977 [8], and the first DTS device was developed in the same year. After a large discussion on DTS organized by Electric

Power Research Institute (EPRI) in 1978, DTS was rapidly promoted in the power industry [6]. In the 1990s, dynamic simulation and object-oriented techniques were introduced into DTS [9]. Since the 21st century, traditional DTS has been unable to meet the needs of the continuously developing smart grid. As artificial intelligence (AI) advances, more intelligent techniques are introduced into DTS, and the intelligent dispatcher training simulator (IDTS) is taking the historical stage. Nico Brose designed the first visualized IDTS in Germany, using software PRINS, which is coupled via a tele-control server with the Root-Mean-Square (RMS) real-time simulation core (with the software PowerFactory) for dynamic grid simulations [10]. A research team from Tomsk Polytechnic University, Russia, built an IDTS with adequate simulation accuracy of any process in the real electric power system, which can also control the equipment circuit-mode states of the power system in real-time [11]. Guo and Lin, from China, based on collaborative simulation on the cloud platform and distributed real-time data processing, improved the offsite collaboration in joint simulation and enhanced the performance and efficiency of the simulation [12,13].

Among the existing research, references [4,7,14–16] summarized the research and application of traditional DTS and outlined the hardware and software structure of mainstream DTS. Most of them divided traditional DTS into three basic functional modules, power system model, control center model, and instructional position. References [17,18] early imagined the development prospects of IDTS based on the booming AI technology, while the latest intelligent technology was not mentioned due to the earlier research time. References [19–25] focused on the embedded techniques of certain function modules of the IDTS, such as building intelligent databases [19], using AI for power system simulation [21,22], and so on.

Looking through the extant research, there are few studies about the state of the art of IDTS. In this paper, firstly, relevant research on DTS in the past two decades is systematically compared and summarized. Secondly, the structure of IDTS and its intelligence is introduced from four aspects, including intelligent power system simulation, intelligent training control, intelligent database management, and intelligent graphic support. Finally, an outlook on the development prospect of intelligent training control is given, which is less studied at present.

2. Traditional Dispatcher Training Simulator

Cultivating a team of experienced dispatchers plays a vital role in preventing accidents and their expansion. The traditional training, however, is basically in the form of classroom teaching, in which the trainees follow the trainers' instructions, participate in anti-accident drills, and summarize accident-handling experiences [26]. These theoretical teachings lack actual combat and are less effective. Trained dispatchers still react slowly and are overwhelmed when they encounter actual accidents, failing to respond timely and effectively at the early stage of fault and causing small-scale accidents to evolve into large-scale catastrophic accidents. The final investigation report on the U.S.—Canada Power System Outage in 2003 pointed out that one of the major causes of the accident was the inexperience of dispatchers at FirstEnergy (FE) and the Midcontinent Independent System Operator (MISO), as well as their inability to take effective measures when the blackout occurred [27].

In the context of the increasing maturity of simulation technology and the unsatisfying effect of traditional dispatcher training, DTS came into being and developed rapidly.

2.1. Structure

The structure of DTS and its relationship with the practical dispatching system is shown in Figure 1 [28]. In the practical dispatching system, dispatchers operate the real power system through the control center, which includes the automatic generation control (AGC) module, the supervisory control and data acquisition (SCADA) module, and the database. DTS, as a simulation of the practical dispatching system, consists of a power system model and a control center model. To ensure the effectiveness of training, the power

system model of DTS should simulate the practical power system as realistic as possible, and the control center model of DTS is a copy of the practical control center, both of which are operated in the same supporting software and hardware as the practical dispatching system. DTS, together with the control center, forms the energy management system (EMS), monitoring and managing the power grid in real-time.

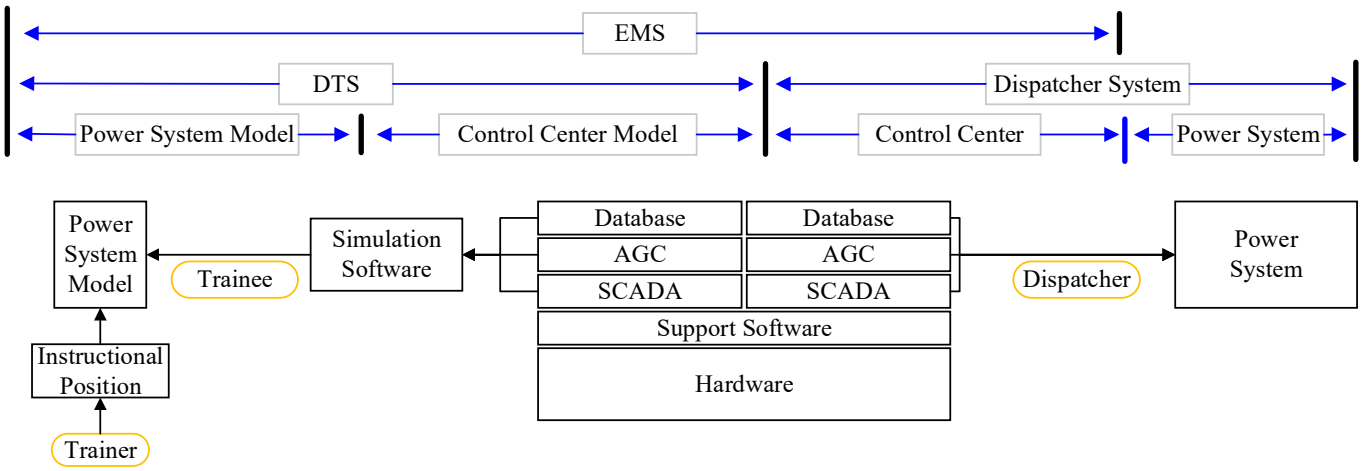

Figure 1. Structure of a DTS (Reproduced with permission of Ref. [28]).

In terms of hardware, there are mainly two layout schemes of the training room for traditional DTS. One is to set up the trainee room and trainer room separately, with the trainee room also serving as a backup dispatching room; the other is to use a part of the actual dispatching room as the trainee room without a fixed trainer room. In DTS systems of provincial dispatching departments or large regional dispatching departments, servers and workstations with UNIX operating systems are often used; in systems such as training centers and substations, PCs with WINDOWS operating systems are often used.

The software of traditional DTS can be divided into two categories. The first includes supporting software and basic application. The supporting software, such as graphics management and web preview, are shared with the practical dispatching system, and they work together to display the simulation results, ensuring the efficient operation of DTS. The basic applications, including SCADA, AGC, and database, analyze data in real-time and guarantee the smooth generation of training plans. The second category is simulation and training software. Simulation software includes network topology, frequency calculation, dynamic current calculation, long-term dynamic simulation, relay protection simulation, etc., and the training software is used to generate training plans, control training processes, evaluate training results, and collect data from the trainee.

2.2. Functionality

The functionality of a traditional DTS consists of three basic modules, i.e., the power system model, control center model, and instructional position [5].

2.2.1. Power System Model

The power system model is the core of a DTS, which includes the power system components model, the control system model, and the power system network topology model. It simulates the change process of power grid operating conditions in normal or fault state, as well as the operation of relay protection devices and automatic safety devices. Besides, it can also simulate the whole process of power system failure caused by the rejection or misoperation of relay protection devices or safety automatic devices [29].

There are mainly three models for the simulation of the primary system (transmission lines, transformers, and other primary equipment):

- Power system static simulation model. This model treats the generator as a power source without electromechanical processes but can be changed statically so as to carry out the dynamic flow calculation on multi-balance nodes.
- Power system fault simulation model. This model is based on static simulation and considers the electromagnetic transient process at the moment of fault so as to calculate the short-circuit current distribution, which serves as the criterion of relay protection action.
- Power system dynamic simulation model. This model considers the dynamics of power system components, electromechanical transient processes, and the impact of boilers and other equipment on the power system, using the time-domain integration method for simulation calculations.

There are mainly four methods to simulate the secondary system (relay protection devices and automatic safety devices) [30]:

- Logic discriminant method. Used in the early days, this method is fast with low maintenance work but requires a more standard main wiring of the power plant. It is applicable to provincial dispatching departments.
- Quantitative discriminant method. This method is accurate but runs slowly and requires high maintenance workload. It is suitable for regional dispatching departments.
- Pre-calculated method. This method calculates the results of protection actions in advance when creating training plans. It is extremely fast but very inflexible, and it can only be applied to pre-defined situations.
- Combination of logic discriminant and quantitative discriminant methods. The difficulty of this approach is the coordination of the two methods.

2.2.2. Control Center Model

The control center model simulates the practical dispatching system to create a virtual working environment for the trainee, mainly consisting of SCADA and AGC simulation, power system analysis, and human-machine interface. To achieve immersive training, the control center model should simulate all the functions of a SCADA/EMS system and be as consistent as possible [15]. There are mainly two approaches to implementation:

- Modify the actual SCADA/EMS system without affecting its normal operation and obtain data for the DTS. This method can provide a more realistic training environment for the trainees, but the system is difficult to be further modified.
- Build a simple SCADA/EMS system that is as similar to the actual system as possible. This method is simple, but it is difficult to be exactly the same.

2.2.3. Instructional Position

The instructional position allows for the monitoring, control, and analysis required during training [5]. This module mainly consists of three functions:

- Trainer's control of the DTS, i.e., preparation before training, operational control during training, and evaluation after training.
- Trainer's control of the simulated grid, i.e., setting faults manually to simulate various incidents in the real grid.
- Trainer's acting as a subordinate dispatcher, i.e., the simulation of basic operation and misoperation.

2.2.4. Dataflow of DTS

As shown in Figure 2, when the system starts, the instructional position first passes the pre-defined model, data, initial power flow, schedule, and other parameters to the power system model. Then the power system model starts the simulation and sends the results to the control center model. The control center model displays the current grid status to the trainee, who then operates accordingly. The operation will be sent back to the instructional

position and then to the power system model to change the grid status. The trainer can monitor and control the training process through the instructional position.

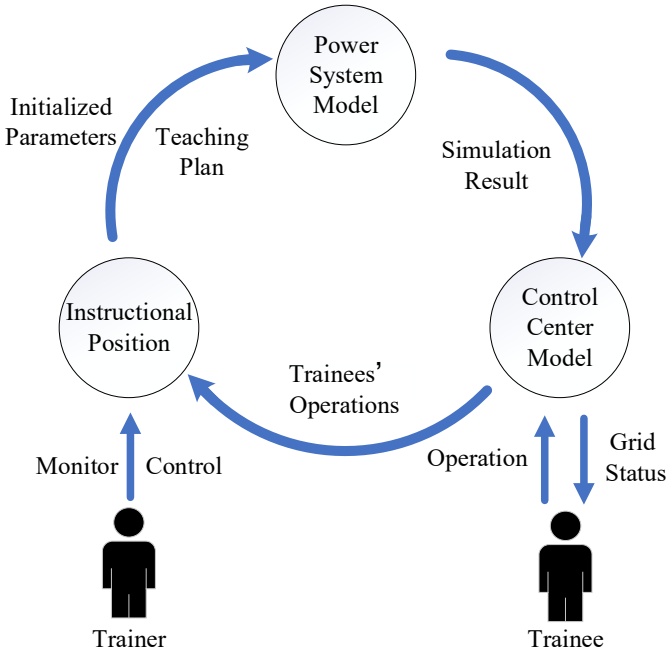

Figure 2. Data flow of a DTS.

2.3. Limitations

As the optimal tool for training dispatchers, DTS is widely used around the world. However, as power systems grow, traditional DTS reveals a number of problems.

- Due to the insufficient data precision and the low maintenance level, the dynamic simulation of DTS cannot achieve accuracy and efficiency at the same time. It may even produce wrong results and mislead the trainees [11].
- With the development of power systems, the operation of power grids has become more interconnected. While the traditional DTS is mainly oriented to a single dispatching center, the model is incomplete, and it is difficult to share information and collaborate during joint exercises [31].
- Traditional DTS focuses on the physical and numerical models, with less consideration of trainees as non-numerical models. It does not introduce the modeling of trainees' knowledge background, thinking habits, dispatching knowledge system, learning path, etc., into the DTS [32].

3. Intelligent Dispatcher Training Simulator

In recent years, to address the limitations of traditional DTSs, academia, and industry have started to explore and introduce intelligent techniques into DTSs. With the rapid development of computer science and artificial intelligence (AI), the symbolic processing capability of computers has been greatly enhanced. The power system is a nonlinear dynamic system, and so is the learning model of trainees, while AI is widely used to solve nonlinear problems. Therefore, simulation technology, solution algorithms, and support software can be combined with AI to develop an intelligent dispatcher training simulator (IDTS).

As shown in Figure 3, there are four subsystems in the IDTS, which are the intelligent power system simulation, intelligent training control, intelligent database management, and intelligent graphic support [17]. The intelligent power system simulation subsystem is designed to improve the simulation accuracy and efficiency with the adoption of intelligent techniques so as to support large-scale power system simulation and inter-regional joint

exercises; the intelligent training control subsystem borrows the idea of adaptive learning so as to improve the effectiveness of dispatcher training; the intelligent database management subsystem provides data management support for the extended functions of the IDTS; and the intelligent graphic support subsystem improves user interaction experience. The functions and techniques of each subsystem are detailed as follows.

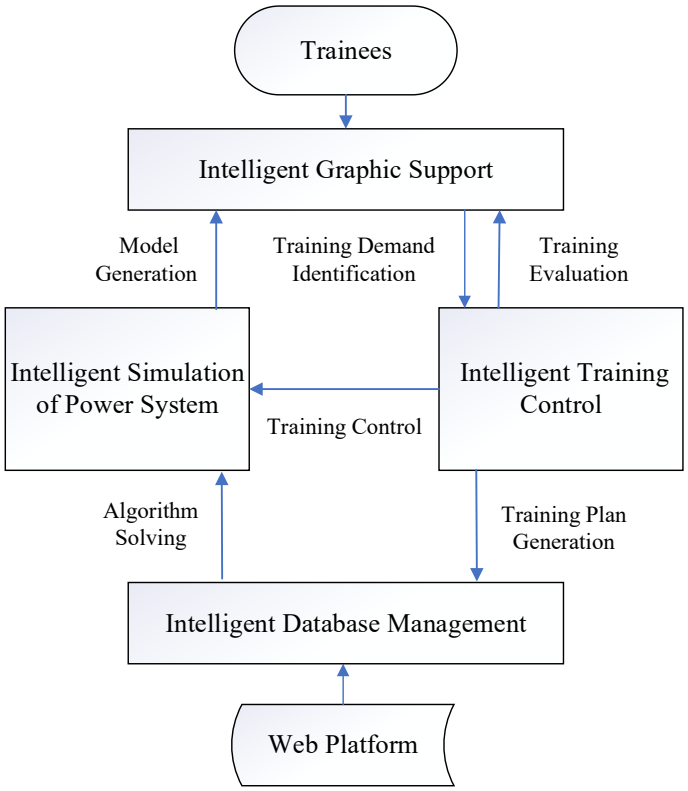

Figure 3. Structure of an IDTS.

3.1. Intelligent Power System Simulation

3.1.1. Functionality

The power system model is the core of the traditional DTS; similarly, the intelligent power system simulation is a vital subsystem of the IDTS. At present, there are still many problems to be studied in power system simulation, such as the limitations of the model, the enormity of modeling, and the puzzling nature of the results, which can be solved by introducing AI technology. Two major functions of this subsystem are intelligent model generation and intelligent model solving.

(1) Intelligent model generation.

Compared with the traditional DTS, the primary system to be simulated in the IDTS is the smart grid, and the secondary system to be simulated is the corresponding dispatching system integrated with the substation monitoring. The system should also realize the simulation of online monitoring, analysis, and early warning of interconnected grids, as well as the simulation of renewable energy integration, control, and dispatch [18]. Currently, research on the application of intelligent simulation techniques in IDTS is widely carried out. Different intelligent simulation techniques enable a complete description of the smart grid, making the simulated grid in IDTS more realistic [21,22,24].

(2) Intelligent model solving.

Dr. T.E. Dy Liacco, who is known as the father of dispatch automation, has described a beautiful blueprint for intelligent dispatching [33]. He argued that by continuously

generating training sets through pattern recognition and decision tree and by automatically learning the features of the power system, an experienced dispatching robot would eventually be formed. This robot would be able to react faster and more accurately than experienced dispatchers when faced with problems [34]. With such dispatching robots being trainees, the IDTS will judge trainers' decisions with better accuracy and efficiency compared with the traditional DTS.

3.1.2. Techniques

Several AI algorithms and techniques can be adopted to realize the above functions [35]:

(1) Expert systems.

Expert systems are one of the most used AI techniques in the field of power systems and dispatching problems [36,37]. Expert systems allow computers to simulate the decision-making process of human experts, solving practical problems that cannot be mathematically modeled and must rely on expert experience [38]. As shown in Figure 4, an expert system solves a specific problem with a knowledge base and an inference engine. The knowledge base is an organized collection of all the facts about power dispatching, and the inference engine interprets the input question and provides an answer according to inference rules. The expert system can solve various power dispatching problems in different regions and under different conditions, effectively alleviating the burden of human trainers in IDTS.

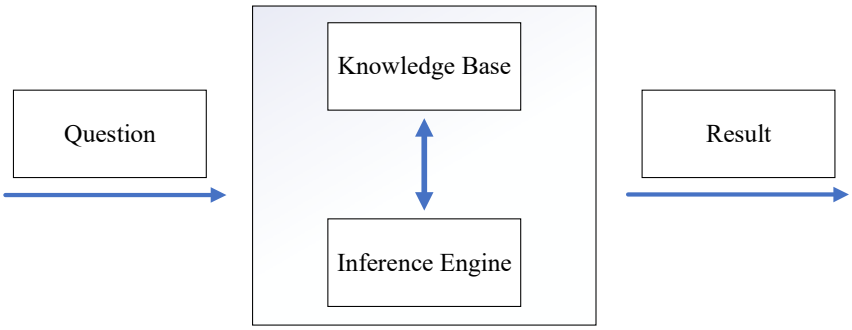

Figure 4. Expert systems.

(2) Artificial neural networks.

Artificial neural networks are inspired by the neural system of humans and can effectively solve nonlinear problems [39]. In power systems, the classification and parallel processing abilities of artificial neural networks can be used for fault detection [40], load forecasting [41,42], security assessment [43,44], automatic control [45], system restoration [46], and many other tasks.

(3) Fuzzy set theory.

Fuzzy set theory can deal with ambiguous, subjective, or imprecise judgments and thus reduce the complexity of the problem [47]. This theory has been applied extensively in the fields of reliability evaluation [48], hybrid algorithm [49], and parameter optimization [50] of power systems.

(4) Heuristic search.

Heuristic search obtains a new solution in a randomized manner, compares it with the previous results, keeps the better one, and iterates until an optimal or approximate solution is obtained [51]. In power system simulation, this method can solve problems with arbitrary objective functions and obtain numerical results with arbitrary precision [52,53].

(5) Cloud computing.

Cloud computing technology, through distributed computing and storage, can reduce hardware investment costs and operation and maintenance costs, as well as enhance

the flexibility of the application architecture [54]. IDTS can be deployed on the cloud platform and use the large grid model on the cloud to conduct joint training among multiple dispatching centers [12,13], thus solving the shortcomings of traditional DTS. Practice proves that cloud-IDTS can realize multi-service and multi-scene co-simulation among dispatching centers. Not only does it improve the off-site interactive coordination capability of joint simulation, but it also realizes the flexible deployment of the simulation environment [55]. The simulation resources are better used and can be better adapted to the rapid development of the power grid.

3.2. Intelligent Training Control

As shown in Figure 5, the intelligent training control subsystem includes four modules: training demand identification module, training plan generation module, training control module, and training evaluation module [17]. These four modules cycle to form a complete training process.

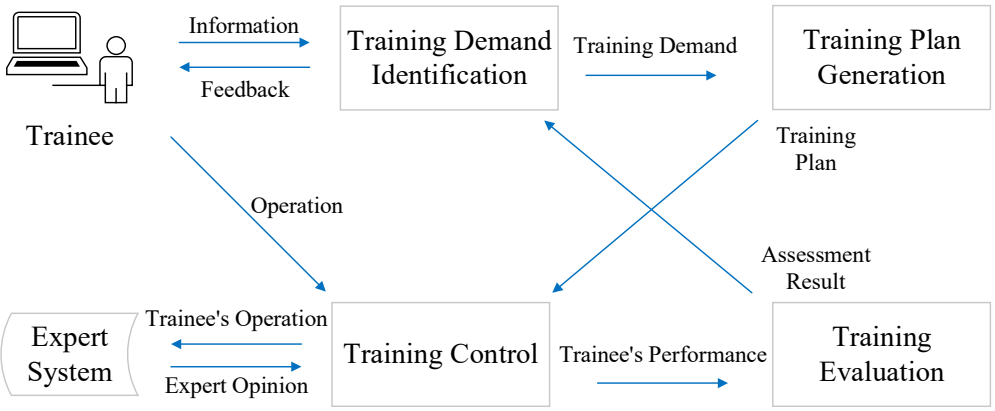

Figure 5. Intelligent training control subsystem.

The training demand identification module is the beginning of the training process. The information to be identified includes the trainee's training records, learning preferences, and the purpose of training.

The training plan generation module develops personalized training strategies and training plans according to the identified training demand. Besides, it will also analyze and modify the training contents to better meet the needs of different trainers.

The training control module controls the training process in real-time according to the training plans. It is the commander of the entire training process. The training control module can use the fuzzy set theory to indicate the understanding level of the trainee and compare the trainee's operations with the results given by the expert system so as to guide the subsequent training. In regular training, this module monitors each step of the trainee's operations, pointing out the deficiencies and providing advice after simulation by the expert system; in the fault handling training, it simulates the inference process of the expert and determines the cause, type, and location of the fault, aiding the trainee's judgment.

The training evaluation module comprehensively assesses the performance of trainees, with the aim of examining the effectiveness of each training phase. At the end of the training, the trainee's operations on accident management are automatically scored, showing the skills they learned and the problems they exposed. This process greatly reduces the human trainer's workload and improves the reasonableness of the grading. After that, the assessment results are fed back to the training demand identification module to update the trainee's record, which then further improves the training plan generation module. The trainee will receive feedback at the end of the training process.

3.3. Intelligent Database Management

Smart grids contain more components compared with traditional grids for which they are horizontally integrated and vertically coherent [19]. Therefore, the IDTS contains more data to be processed. This imposes requirements on the intelligent database management subsystem for simple maintenance, convenient expansion, fully functional, real-time control, and easy operation.

The required functions of the intelligent database management subsystem include:

- Manage all static and dynamic data in the power grid model and support users to query, update, backup, and restore data.
- Provide data sources for all modules and support data exchange between modules.
- Support graphic database for editing, saving, and reproducing graphic data.
- Provide an interface to EMS, which is the key to integrating DTS with EMS.

To fulfill the above requirements, this module should be built as follows.

The database should contain component model parameters, network model parameters, system parameters, simulated SCADA data, training data, graphical data, etc.

Two databases, an offline database, and an online database, need to be established and coordinated with each other [56]. The training program is set up and initialized with the offline database. Relevant model parameters will be passed into the intelligent power system simulation subsystem to start the simulation, and the simulation results will be read from or written to the online database. The graphic module obtains simulation results from the online database and displays them to the trainer and trainee. The trainee performs operations that modify the online database, and the intelligent power system simulation subsystem simultaneously reads in data and re-simulates.

The offline database is managed by ORACLE and can be exported in various forms as required. It supports creating, retrieving, updating, and deleting (CRUD) operations with high reliability, fault tolerance, and self-recovery capability [57], which can guarantee the integrity and security of the database.

Data sharing in online databases can be realized through the shared memory mechanism in UNIX systems, which can provide continuous storage that can be accessed by different processes [58]. The use of an online database can significantly accelerate data access, improving the real-time performance of IDTS.

3.4. Intelligent Graphic Support

The intelligent graphic support subsystem is oriented to trainees and trainers, mainly consisting of diagrams of electrical wiring, power flow, power generation, device configuration, network topology, etc. [59]. It displays the operating conditions of the simulated grid and allows trainees to operate directly on the graphic interface.

Traditional graphic support systems often suffer from the following problems:

- The graphic editing module is designed in a process-oriented way, with individual programming for each component, which is not scalable and has a high maintenance workload [60].
- The network topology module does not take full advantage of the graphical data for analysis and requires separate preparation of topology data.
- The graphical display cannot highlight the specific connection and thus cannot effectively check whether the power system calculation results are correct [61].

To deal with these problems, the intelligent graphic support subsystem mainly includes the graphics editing module, data management module, display, and dynamic update module, and printing module.

- The graphics editing module contains the commonly used basic symbols (points, lines, circles, etc.), electrical components (generators, transformers, etc.), and vector words. An object-oriented approach is used to encapsulate the individual graphic elements in the form of classes, and then different types of data are placed in different layers.

- The data management module mainly uses large commercial databases, such as ORACLE, to meet security and efficiency requirements.
- The display and dynamic update module support dynamic graph update, screen switching, and graph zooming. It also allows trainees to perform operations on the graph [62].
- The graphics printing module converts vector graphics to PostScript files for direct output or converts graphics windows to X Windows files for output with the XPR command.

4. Prospect of Intelligent DTS: Adaptive Learning

Currently, most research on the IDTS focuses on intelligent power system simulation, with less research on intelligent training control. The dispatcher training process suffers from a low automation level and still requires the participation of human trainers throughout the process. Meanwhile, adaptive learning is a flourishing technique in the field of intelligent tutoring, showing great potential in IDTS.

4.1. Overview of Adaptive Learning System

Adaptive learning means that, according to the different learning styles, knowledge levels, and cognitive abilities of different students, targeted and personalized learning services are provided. In general, adaptive learning services include targeted learning content pushing, personalized learning path recommendation, intelligent problem coaching, dynamic assessment, feedback, etc., which can effectively improve the learning efficiency and effectiveness of students [63,64].

In 1996, Brusilovsky proposed Adaptive Educational Hypermedia Systems (AEHS) [65], which combines the hypermedia system, adaptive system, and intelligent teaching system in one, and is known as the first practical adaptive learning system. Since then, with the continuous integration of AI and data science with educational science, cognitive psychology, and neuroscience, new types of adaptive learning systems have emerged. Adaptive learning platforms such as Knewton, Coursera, and Smart Sparrow have been launched, generating personalized learning suggestions for students based on big data, knowledge mapping, and recommendation models.

Throughout recent years, adaptive learning systems (ALS) have been emerging, among which the AEHS model proposed by Brusilovsky is the most classic. Although many different adaptive learning models have been proposed by academic and engineering communities, most of them are still based on the architecture of AEHS, and the main technical breakthrough lies in the embedded algorithms of each component [66–68]. The architecture of AEHS is shown in Figure 6, including the student model, domain model, pedagogy model, and interface model [69]. The four models are connected through an adaption engine, among which the student model, domain model, and adaption engine are the heated topics of research [65].

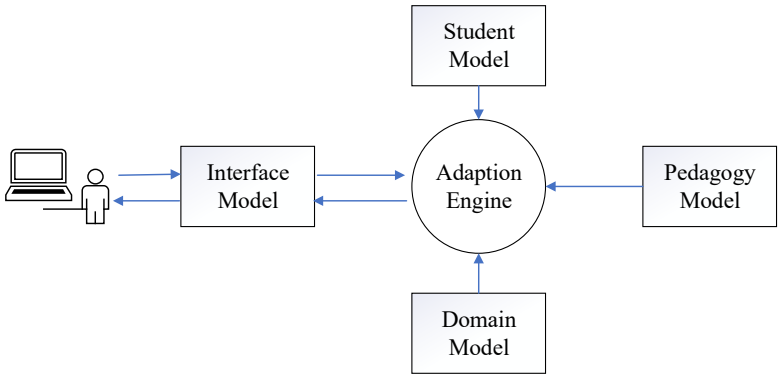

Figure 6. AEHS Model.

4.2. Student Model

The student model is one of the core components of ALS, which describes the characteristics of students. It demonstrates the individual differences among students and is the basis for the system to provide personalized services [70]. The effectiveness of learning in ALS depends greatly on the design of the student model [71].

The student model consists of three major parts, basic information, learning style, and cognitive level. Among them, basic information describes the static information of students, such as name, student/employee ID, gender, age, major/position, learning record, etc. The learning style and cognitive level are the keys of the student model, which represent the dynamic information of students and jointly characterize student status.

In 1979, Keefe first defined learning style as "a relatively stable, composite indicator of students' emotional, physical, and cognitive characteristics that also interact with the learning environment" [72]. Briefly, learning style is the personalized learning performance of each individual, which indicates their learning choices and distinctions. Drawing on other models, such as the Kolb learning style model, Felder proposed the Felder-Silverman Index, as shown in Table 1 [73], which divides students' learning styles into four dimensions: perception, input, processing, and comprehension. It is currently the most widely used learning style model. In the intelligent training control subsystem, trainees should take a Soloman learning style questionnaire at registration to initialize their four-dimensional learning style [74]. During the learning process, the intelligent training control subsystem also collects and analyses trainees' learning records to continuously update their learning styles.

Table 1. Felder-Silverman Index.

Dimension	Style	Description
Perception	Sensing	Prefer concrete thinking, practical, concerned with facts and procedures
	Intuitive	Prefer conceptual thinking, innovative, concerned with theories and meanings
Input	Visual	Prefer visual representation, pictures, diagrams, and flow charts
	Verbal	Prefer written and spoken explanations
Process	Active	Prefer to try things out, working with others in groups
	Reflective	Prefer thinking things through, working alone or with familiar partners
Comprehension	Sequential	Prefer linear thinking, orderly, learning in small incremental steps
	Global	Prefer holistic thinking, systems thinkers, learning in large leaps

Cognition refers to the ability to acquire, apply, and process information, which is the basis for humans to cognize the universe [75]. In ALS, the system always recommends learning tasks with different difficulties according to students' different cognition levels so as to design personalized learning paths for each student. In the intelligent training control subsystem, the student's cognitive level will be scored from 1 to 5, with 1 indicating extremely weak cognition and 5 indicating extremely strong cognition. At registration, a base score (e.g., 3) can be set by the trainer, or the trainee can take a simple cognitive level test to obtain an initial score. During the subsequent learning process, the system will update the trainee's cognitive level by monitoring their learning performances.

4.3. Domain Model

The domain model describes the constituent elements of a domain and their structure, representing the interrelationships between the elements within the domain [76]. Domain knowledge provides a source of data for personalized learning, while the domain model is the structure of domain knowledge. Therefore, the way it is modeled can directly affect the effectiveness of the ALS's recommendation.

Mustafa and Sharif divided the domain model into two parts, the knowledge sub-model and the resource sub-model [77]. As shown in Figure 7, the knowledge sub-model describes the knowledge relationships, which are usually represented by nodes and arcs of the concept network, where nodes represent knowledge points, and arcs represent their relationships. The hierarchical representation is usually divided into four levels: compound concepts, concept nodes, concept sub-nodes, and concept atoms, corresponding to chapters, sections, paragraphs, and knowledge points in the course content. The resource sub-model consists of resource objects, such as web videos, e-textbooks, digital books, etc. The interconnection between learning resources enables the knowledge content to support specific concepts in the domain model.

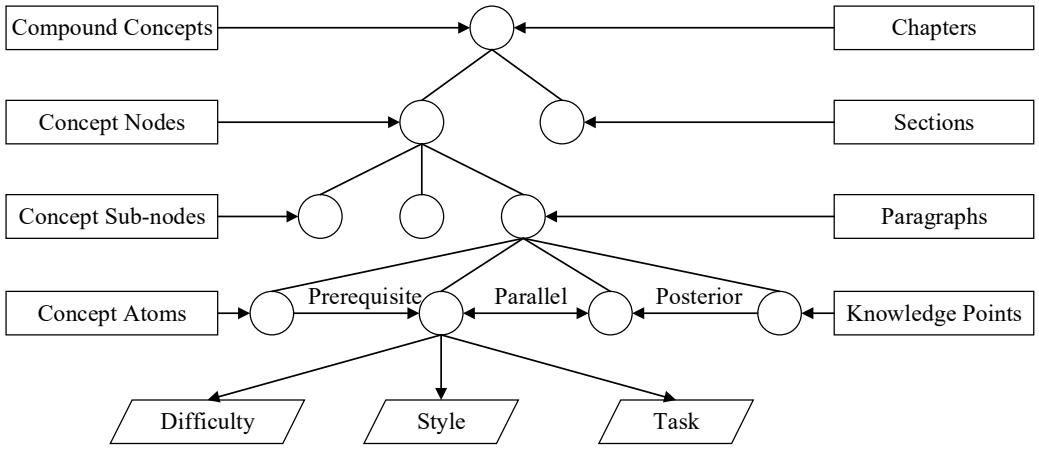

Figure 7. Knowledge sub-model.

In the intelligent training control subsystem, each concept atom contains a minimum unit of dispatching knowledge with relationships between each other, including prerequisite, parallel, and posterior relationships. Each concept atom contains attributes such as difficulty, style, and learning task. The difficulty coefficient and knowledge style match with the trainee's personality (respectively, the cognitive level and learning style), so the most appropriate concept atom could be pushed to the student by the adaption engine.

The storage of the domain model involves three databases: the strategy database, the course database, and the resource database [78].

- The strategy database stores the difficulty coefficient and knowledge style of each concept atom as well as the relationship between atoms.
- The course database stores the descriptive information of concept atoms, such as serial numbers, descriptions, and exercises.
- The resource database stores resource information such as names, types, and links.

4.4. Adaption Engine

The adaption engine develops learning service strategies based on the student model (the student's current learning style, cognitive ability, learning records, etc.) and learning goals. It dynamically arranges relevant learning contents and resources, as well as manages the learning process in real-time, continuously monitoring, modifying, and maintaining the student model [79]. When the student fails to achieve learning goals or is less efficient, the learning strategy will be updated accordingly and timely. During this process, the engine continuously corrects and optimizes the rules and evolves itself.

There are two core functions of the adaptive engine, learning diagnosis and learning path recommendation [80].

4.4.1. Learning Diagnosis

ALS diagnoses students' learning in two aspects, cognitive level and learning emotion.

(1) Diagnosis of cognitive level

ALS is linked to the exercise system, performance analysis system, etc., and uses a multidimensional diagnostic approach to comprehensively assess the learning status of students. Meanwhile, students are placed in groups for comparative analysis. Their learning levels among similar users are analyzed comprehensively to obtain the relative values of their cognitive levels. The learning outcomes of students are analyzed from various aspects, such as the progress curve, knowledge mastery level, and position in the group.

(2) Diagnosis of learning emotion

Students' emotional information can be analyzed through facial expressions and interactions with others during the learning process. In particular, expression-based emotional diagnosis captures students' facial expressions in real-time; text-based emotional diagnosis captures emotional information from students' messages or voices during online communication with others. Then the emotional tendency can be calculated according to the emotional dictionary.

After diagnosing the student's learning status, the cognitive level in the student model should be adjusted accordingly. Feedback on the student's learning style should also be given based on the knowledge style of each concept atom and the diagnosis results of the student's learning process.

4.4.2. Learning Path Recommendation

The ALS's recommendations on learning paths are divided into two levels, one for the knowledge learning path and the other for the resource presentation path.

(1) Knowledge learning path

The ant colony algorithm was proposed by Italian scholar Dorigo Morigo in 1991 [81], in which ants leave pheromones on the paths they take during foraging so that other ants can gradually form an optimal foraging path by identifying the path with the largest pheromone to move forward [82]. This algorithm can be applied to the recommendation of the learning path in the intelligent training control subsystem. The students are compared with ants, the learning target is compared with the ant's food, and the learning results of different concept atoms are compared with the pheromones left by the ants. Thus, an optimal path to master all the dispatching knowledge will be gradually formed and recommended to the students in the training process.

(2) Resource presentation path

Each segment of the learning path contains a number of concept atoms that are located at the same level and are in juxtaposition. The order in which these concept atoms are pushed to the students is the resource presentation path. In the intelligent training control subsystem, the student model records the current learning style and cognitive level of each student, and the domain model describes the difficulty and style of each concept atom. Therefore, the system can comprehensively calculate the association between the student and the knowledge, namely, the compatibility between the student's cognitive level and the knowledge's difficulty, as well as the association between the learning style and the knowledge style. A ranking of concept atoms will be generated based on their suitability for students to learn at the moment, based on which the concept atoms will be pushed to the student in turn.

5. Conclusions

With the ever-increasing integration of intermittent generation such as wind power and solar power, the stability of a power system becomes more and more complex. Thus the demand for skilled dispatchers keeps growing. As the optimal tool for dispatcher training, DTS is in urgent need of technical innovation. This paper reviews the research and application status of IDTS and presents the outlook of its development trend.

First, we sort out the structure and functions of traditional DTS and point out its limitations in the context of the smart grid. Then, we introduce the recently booming IDTS and analyze how AI techniques can enhance its functionality from four aspects: intelligent power system simulation, intelligent training control, intelligent database management, and intelligent graphics support. Finally, for the less studied intelligent training control subsystem, we propose to introduce adaptive learning techniques. By modeling the trainee and domain knowledge, a personalized model of the knowledge learning path and resource presentation path will be established.

Introducing artificial intelligence into the development of an intelligent DTS will help to train dispatchers with systematic knowledge and skills within the context of the smart grid, which will be a promising aspect of future research.

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