The Impact of Artificial Intelligence Technology on the Development of New Energy

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Abstract: *Artificial intelligence is quietly reshaping the landscape of the new energy sector. This article systematically reviews how AI technology is "taking root" in the field of new energy—from national top-level design to specific power generation and dispatch scenarios, and onward to what the future might hold.*

Let's start with the big picture. According to the national "Implementation Opinions on Promoting the High-Quality Development of Artificial Intelligence +Energy, by 2027, we aim to preliminarily establish an innovation framework integrating energy and AI; by 2030, China's AI technologies and applications in the energy sector are expected to reach world-leading levels. These goals are quite concrete, providing both a timeline and a clear roadmap.

When it comes to specific applications, AI's reach has extended into every corner of the new energy landscape: from power forecasting and intelligent operation and maintenance, to grid dispatch and virtual power plants, and on to energy storage optimization—AI's presence can be felt in virtually every link. For instance, using AI for power forecasting can push accuracy above 95%; intelligent O&M has made the concept of "unattended operations" a reality; grid dispatch response times have been compressed from five minutes to 90 seconds. These aren't just theoretical—they're delivering tangible results: operational efficiency is up, and reliability is more solid.

Of course, the path of technological application hasn't been entirely smooth. Right now, there are several tough challenges that can't be ignored. First, there's the technology itself: the "black box" problem with algorithms hasn't been fully resolved, and they can still stumble in extreme scenarios. Second, there are data barriers—everyone guards their own turf, and data sharing mechanisms have yet to gain traction. Third, there's energy consumption: large models are power-hungry, which actually runs somewhat counter to our energy-saving and carbon-reduction goals. Beyond these, information security risks and a shortage of interdisciplinary talent are also hurdles that can't be sidestepped. At the end of the day, if we want AI to truly take on the heavy lifting in the new energy sector, these are challenges we have to confront head-on[1].

Taking a longer-term view, the direction is actually quite clear. With continued breakthroughs in trustworthy AI technologies, the deepening integration of digital twins and large models, and the gradual alignment of "computing power" and "electricity" coordination mechanisms, the energy system of the future is likely to move toward "second-level response, autonomous optimization, and panoramic visibility." By then, AI will no longer be just a nice-to-have add-on—it will be embedded naturally into every corner of the energy system, much like water and electricity.

Keywords: *artificial intelligence; new energy; smart grid; energy transition; digital twin*

1. Introduction

Right now, the global energy sector is undergoing a profound structural transformation—put simply, fossil fuels are gradually stepping back, and renewable energy is making its way to center stage. By the end of July 2025, China's cumulative installed capacity for wind and solar power had surged to 1.68 billion kilowatts, accounting for 46% of the nation's total installed capacity. A decade ago, these numbers would have been unimaginable.

But every coin has two sides. New energy has an inherent characteristic—it's at the mercy of the weather. When the wind blows hard and the sun shines bright, output surges; when the weather turns, output can plummet dramatically. In extreme cases, wind power output can drop by more than 85% in a short period, while solar power follows the clouds, with intraday fluctuations as volatile as a roller coaster. This poses a considerable challenge for the power grid: the system must maintain balance at all times, but traditional dispatch methods, frankly, are struggling to cope with such complexity.

And that's precisely where artificial intelligence has stepped onto the scene. Moreover, its arrival hasn't been gradual—it's come with accelerating momentum, moving from the laboratory into the real world, transitioning from experimental exploration to tangible value creation. In 2024, the "Artificial Intelligence+" initiative was written into the government work report for the first time; in 2025, the State Council issued dedicated "Opinions on Deeply Implementing the 'Artificial Intelligence+' Action." The energy sector quickly followed suit, with the National Development and Reform Commission and the National Energy Administration jointly releasing a heavyweight document: the "Implementation Opinions on Promoting the High-Quality Development of 'Artificial Intelligence +' Energy." The targets set within are quite clear: by 2027, five or more specialized large models in the energy field should be genuinely operational, with one hundred typical application scenarios explored; by 2030, China's AI technologies and applications in the energy sector are expected to reach world-leading levels[2].

Simply put, integrating AI with new energy isn't just a technological choice for coping with the pressures of the energy transition—it's also an unavoidable path toward achieving the broader "dual carbon" goals. What this article aims to do is to lay it all out and have an open discussion: how policies are driving change, where technologies are being applied, what successful cases look like in practice, and those unavoidable pitfalls and challenges along the way. Ultimately, the goal is to provide a reference for anyone interested in this interdisciplinary field—something that's both accessible and practical.

2. Top-level Design at the National Level

2.1 Phased Development Goals

The "Implementation Opinions on Promoting the High-Quality Development of 'Artificial Intelligence +' Energy" delineates the phased objectives and strategic pathways for the development of this sector.

Specifically, the document establishes a phased strategic planning framework. By 2027, the core objective is to preliminarily establish the foundational system for the integrated innovation of energy and artificial intelligence, while solidifying the foundation for the synergistic development of computing power and electricity. The quantitative targets for this phase encompass the following aspects: promoting the in-depth application of no fewer than five energy-specific large models in key industries such as power grids, power generation, coal, and oil and gas; identifying and cultivating over ten key demonstration projects with replicability and ease of promotion; exploring and delineating the empowerment pathways for one hundred typical application scenarios; researching, formulating, and refining one hundred relevant technical standards; and concurrently, fostering a number of industry-level research, development, and innovation platforms[3].

By 2030, the overarching strategic goal is to achieve a world-leading level in AI-specific technologies and their applications within the energy sector. By this time, the synergy mechanism between computing power and electricity will be further improved, with significant breakthroughs expected in core areas such as intelligent power grid dispatch, intelligent exploration of energy resources, and intelligent forecasting for new energy power generation. Furthermore, cutting-edge technological forms such as embodied AI and scientific AI will realize the transition from research and development to practical application in key energy scenarios. This strategic plan provides a clear timetable and a well-defined roadmap for the deep integration of artificial intelligence technology with the energy industry.

2.2 Layout of Eight Key Application Scenarios

The "Implementation Opinions on Promoting the High-Quality Development of 'Artificial Intelligence +' Energy" systematically deploys eight key application scenarios for "Artificial Intelligence +" across major energy categories, including coal, electricity, oil, and natural gas. These scenarios specifically cover the domains of power grids, new energy business formats, new energy, hydropower, thermal power, nuclear power, coal, and the oil and gas sector. This layout embodies the strategic approach of "comprehensive coverage with breakthrough focuses": it strives to promote the digital and intelligent transformation and upgrading of traditional fossil energy, while simultaneously fostering the deep integration of new energy and emerging energy business formats with artificial intelligence technology. Examined from the perspectives of industry typology and transition pathways, this systematic arrangement is designed to holistically balance both the optimization of the existing energy stock and the development of incremental growth, thereby providing a clear practical framework for the comprehensive empowerment of the energy industry by artificial intelligence technology.

2.3 Policy Value and Practical Significance

As a strategic deployment at the national level, the issuance of the "Implementation Opinions on Promoting the High-Quality Development of 'Artificial Intelligence +' Energy" carries multiple layers of policy value and practical significance. Firstly, it establishes clear directional guidance for the development of artificial intelligence in the energy sector, effectively promoting the concentration of innovative elements such as capital, talent, and technology towards key areas. Secondly, the policy addresses common bottleneck issues—including computing-power synergy, data sharing, and standardization—from a holistic, overarching perspective, helping to avoid low-level redundant construction and resource misallocation. Finally, it aims to construct a collaborative innovation system characterized by government guidance, enterprise leadership, support from research institutions, and extensive participation from social capital. This provides both an institutional guarantee and an ecosystem of support for the deep integration of "Artificial Intelligence +" within the energy sector[4].

3. Multi-dimensional Applications of AI in the New Energy Sector

3.1 Power Forecasting and Load Forecasting

OAccurate forecasting serves as the fundamental prerequisite for ensuring the stability of new energy grid integration. Constrained by the simplifications inherent in parametric schemes, traditional physical models struggle to effectively characterize the nonlinear fluctuation patterns of new energy output under complex meteorological conditions. In contrast, artificial intelligence models can significantly enhance forecasting accuracy by uncovering the intricate correlations implicit in massive historical datasets.

In the domain of new energy power forecasting, deep learning methods such as Long Short-Term Memory networks, hybrid Convolutional Neural Network-LSTM models, and Random Forests have been widely applied to photovoltaic output and wind speed prediction. The Dispatching and Control Center of State Grid Xinjiang Electric Power has introduced artificial intelligence technology, achieving a power forecasting accuracy exceeding 93% for nearly one thousand new energy stations under its jurisdiction, thereby providing robust support for intraday dispatching control. The "Qingyuan Large Model" developed by CHN Energy has achieved a significant improvement in wind speed prediction accuracy, driving a 2.8 percentage point increase in new energy power forecasting accuracy.

In the domain of load forecasting, AI algorithms possess the capability to uncover potential spatiotemporal correlations in power load patterns. The provincial-prefectural integrated load forecasting management system deployed by Guangdong Power Grid can complete fully automated forecasting for approximately 1,300 bus nodes within minutes. Actual operational data indicates that the system's load forecasting achieves an average accuracy of 97% on weekdays, while its day-ahead bus load forecasting accuracy reaches 82.4%.

3.2 Intelligent Operation & Maintenance and Equipment Diagnostics

TNew energy stations are typically characterized by geographically dispersed distribution and complex operational environments, posing the dual challenges of low efficiency and high costs for traditional manual inspection models. The AI-empowered intelligent operation and maintenance technology system is driving the industry's evolution towards reduced-crew and unmanned operation models.

Computer vision technology constitutes the core technical support for intelligent inspection. In transmission line inspection scenarios, unmanned aerial vehicles equipped with AI recognition systems enable rapid identification of typical defects such as insulator contamination and foreign objects on equipment. The "Guangming Large Model" developed by State Grid Corporation of China achieved an overall detection rate of 88.06% for 45 categories of critical defects during centralized testing of transmission UAV inspection image recognition. The XS-1000D, an AI data analysis platform for pumped storage deployed by China Southern Power Grid, has achieved a manual inspection substitution rate exceeding 90%, generating annual economic benefits of approximately 17.6 million yuan.

Equipment failure warning represents another significant application scenario where AI empowers new energy operations and maintenance. The "Tianheng · Smart Storage Platform" developed by Contemporary Amperex Technology Co. Ltd. integrates AI algorithms with mechanistic models, enabling failure warnings seven days in advance with an algorithm accuracy exceeding 99.99%, thereby reducing unplanned downtime losses at energy storage power stations by 75%. The "Intelligent Brain" embedded in Huawei's fully liquid-cooled ultra-fast charging piles employs multimodal data fusion diagnostic technology, achieving a fault identification accuracy of 98.3% and reducing the mean time to repair from four hours to 1.5 hours.

3.3 Intelligent Grid Dispatch and Virtual Power Plants

The high-penetration integration of new energy is driving the transformation of grid dispatch paradigms from traditional experience-driven approaches to data-driven models. Artificial intelligence technology, through multi-dimensional data fusion and dynamic optimization of decision-making, has significantly enhanced the balancing and regulation capabilities of power systems.

The "Smart Dispatch Hub" developed by State Grid Corporation of China adopts a hybrid architecture integrating deep reinforcement learning and graph neural networks. By incorporating over 100,000 dimensional features—including meteorological satellite data, real-time new energy output, and user load characteristics—it has reduced decision response latency from five minutes under traditional models to 90 seconds. During the peak summer period of 2025, this system dispatched a cumulative total of 1.2 trillion kilowatt-hours of cross-regional electricity, contributing to an increase in the new energy accommodation rate to 97.3%.

3.4 Energy Storage Optimization and Multi-Energy Synergy

Energy storage technology serves as a core instrument for smoothing fluctuations in new energy power generation and enhancing the flexibility of power systems. The "AI-BMS System" developed by Contemporary Amperex Technology Co., Limited (CATL), based on multi-scale fusion modeling technology, has achieved an integrated intelligent management framework that encompasses short-term charge-discharge strategy optimization, mid-term battery health management, and long-term failure warning. Application data indicates that this system has improved energy storage utilization efficiency from 60% to 85% and extended battery cycle life to 4,500 cycles.

In the field of multi-energy complementarity, artificial intelligence technology is driving the transformation of energy systems from single-energy supply paradigms towards integrated energy utilization. The "Wind-Solar-Storage-Hydrogen" demonstration project in Ulanqab, Inner Mongolia, employs predictive technology that integrates physical models with data-driven approaches, achieving a reduction in the wind curtailment rate from 12% to 4.8% and lowering the levelized cost of energy from 0.35 RMB/kWh to 0.28 RMB/kWh. Relying on a digital twin platform for system-level collaborative optimization, the Shenzhen Mawan Smart Energy Ecological Park has increased its comprehensive energy efficiency from 42% to 65% while reducing carbon emission intensity by 28%. These practices demonstrate that artificial intelligence technology possesses significant potential for enhancing both the economic viability and low-carbon performance of multi-energy complementary systems.

3.5 Electricity Market Trading Decision-Making

The application of artificial intelligence technology in the domain of electricity market trading is increasingly deepening. According to relevant practical data, AI algorithm-based electricity spot market trading systems can achieve provincial-level new energy power forecasting accuracy of 95%, load forecasting accuracy of 98%, and electricity price forecasting accuracy of 90%. State Grid Shanxi Electric Power Company integrated its electricity trading platform with the "Guangming Large Model," and power sales companies utilizing this trading decision support system have achieved profits on the scale of tens of millions of yuan. Furthermore, following the application of the "Qingyuan Large Model" at the CHN Energy Shanxi Huozhou Power Plant, its nodal electricity price forecasting accuracy improved by 6.2 percentage points compared to traditional methods. These cases demonstrate that artificial intelligence technology exhibits significant application value in enhancing forecasting precision and trading decision efficiency within electricity markets.

4. Challenges and Risks of AI in New Energy Development

4.1 Algorithmic Opacity and Failure in Extreme Scenarios

Within energy systems, the margin for error in decision-making processes is exceedingly narrow, with operational safety objectives consistently anchored to the extreme reliability requirement of "zero accidents." However, current mainstream deep learning models commonly suffer from the problem of "algorithmic opacity," wherein their internal decision-making mechanisms lack interpretability and traceability. Consider, for example, an artificial intelligence dispatch algorithm used by a provincial power grid. When encountering a sudden 20% load surge, anomalous responses in the activation thresholds of the model's hidden layer neurons caused the system to misjudge the emergency regulation command as data noise and refuse to execute it, ultimately triggering a cascading failure involving overload trips at twelve substations. This case highlights the systemic risks that insufficient algorithmic interpretability can precipitate under extreme scenarios.

Furthermore, inadequate model generalization capability constitutes another critical bottleneck restricting large-scale deployment. Current AI models are typically trained on historical data from specific scenarios. When deployed in new environments with vastly different geological conditions, regional characteristics, or operational regimes, model performance often exhibits significant degradation. This phenomenon indicates an urgent need to enhance the transfer learning and domain adaptation capabilities of current models to meet the application demands of highly heterogeneous and dynamically changing energy systems[5].

4.2 Quality, Sharing, and Compliance: A Triple Threshold

Data constitutes the core element driving artificial intelligence models; however, within the energy sector, the effective utilization of data confronts multiple practical predicaments.

Data quality issues are prominent: The complex on-site environment of the energy industry renders sensor data susceptible to factors such as electromagnetic interference and equipment aging, resulting in prevalent problems including low signal-to-noise ratios, high missing data rates, and frequent outliers. Concurrently, the acquisition cost of high-quality annotated data is prohibitively high. Particularly in scenarios involving scarce samples, such as equipment failures, the issue of sample imbalance is further exacerbated, making it difficult to construct comprehensive datasets that meet the requirements for AI training.

Data sharing barriers are significant: The boundaries of data rights and responsibilities among different entities—including power generation enterprises, grid companies, and end-users—remain unclear. There is a lack of secure and trustworthy data sharing incentive mechanisms and standardized circulation platforms. This situation leads to the widespread phenomenon of "data silos," constraining the potential for collaborative optimization and value extraction across the entire industrial chain through artificial intelligence technology.

Privacy compliance risks are pronounced: User electricity consumption data falls within the scope of personal privacy protection. Under the framework of laws and regulations such as the "Personal Information Protection Law of the People's Republic of China," how to achieve the secure utilization of data value while ensuring compliance has emerged as a major challenge demanding urgent resolution.

4.3 The Sustainability Paradox of Green Development

The energy consumption associated with artificial intelligence computing power exhibits an exponential surge in tandem with the expansion of model scale, a trend that creates an inherent tension with the energy sector's objectives of energy conservation and carbon reduction. As application scenarios such as large model training and digital twins undergo large-scale deployment, the energy consumption of computing infrastructure is projected to experience leapfrog growth. Take a certain intelligent computing center as an example: its annual electricity consumption reaches 320 million kilowatt-hours, approaching the total residential electricity usage of a medium-sized county—a figure that underscores the severity of the computing power energy consumption challenge.

The "East-to-West Computing Resources Transfer Project" provides a strategic opportunity for optimizing the spatial distribution of computing power and advancing green computing development. However, low-carbon technological pathways such as renewable energy power supply and waste heat recovery and utilization currently remain in the exploratory stage, with scalable technical solutions yet to be established. Furthermore, the absence of established carbon footprint accounting standards and monitoring management systems for the full lifecycle of computing infrastructure constrains the coordinated advancement of both the artificial intelligence industry and energy transition objectives.

5. Trends Towards the Era of Intelligent Energy

5.1 Breakthroughs in Trustworthy AI Technologies

To address the challenges of algorithmic opacity and decision-making uninterpretability faced by deep learning models in core energy production processes, enhancing model interpretability, robustness, and physical consistency will become a key focus of future technological research and development. Specifically, technological pathways such as Explainable AI, causal inference, and Physics-Informed Neural Networks aim to embed physical mechanisms into deep learning architectures. This approach enables models to maintain high-precision predictive capabilities while possessing traceable and verifiable decision-making logic, thereby overcoming the application thresholds in critical energy scenarios. Furthermore, the establishment of national-level AI model testing and validation platforms will provide authoritative technical support for model performance evaluation, reliability verification, and robustness testing, safeguarding the large-scale safe application of artificial intelligence technology in the energy sector from an institutional perspective.

5.2 The Convergence of Digital Twins and Large Models

The deep integration of digital twin technology with large language models constitutes a significant frontier direction in the intelligent evolution of energy systems. Digital twins, by constructing high-fidelity virtual replicas of physical entities, enable real-time system monitoring and multi-scenario simulation and projection. Large language models, leveraging their cross-modal semantic understanding and decision-making reasoning capabilities in complex scenarios, endow systems with higher-level cognitive intelligence. The technological pathway based on a hybrid architecture integrating digital twins and large language models can effectively enhance the predictive analysis accuracy, resilience response capabilities, and autonomous decision-making level of energy systems across multi-dimensional spatial and temporal scales, thereby propelling the evolution of system operation modes towards the intelligent direction of "real-time response and autonomous optimization."

5.3 Refinement of Computing-Power Synergy Mechanisms

The coordinated development of computing infrastructure and power systems has been elevated to a national strategic priority. The "Implementation Opinions on Promoting the High-Quality Development of 'Artificial Intelligence +' Energy" explicitly proposes the need to establish synergistic development mechanisms for the deep integration of computing power and electricity, thereby supporting the large-scale application and sustainable development of artificial intelligence technology in the energy sector.

Examining future evolutionary trends, this coordinated development primarily manifests across three dimensions: First, synergy in spatial layout, which involves promoting the coordinated planning of computing centers and renewable energy bases, leveraging the "East-to-West Computing Resources Transfer Project" to achieve green power supply for computing demands. Second, synergy in operational dispatch, which entails guiding computing loads to participate as flexible resources in grid demand response, achieving bidirectional interaction and dynamic balance between computing power and electricity through intelligent dispatch. Third, synergy in regulatory governance, which involves incorporating the full lifecycle carbon footprint of computing infrastructure into regulatory frameworks, thereby driving the application and iteration of green and low-carbon technologies within the computing domain.

5.4 Inclusive Development and Global Governance

In the process of promoting AI-enabled new energy development, full consideration must be given to the actual needs and interests of developing countries and vulnerable groups. Low- and middle-income countries generally face structural constraints such as scarce data resources and weak institutional capacities, placing them in a relatively disadvantaged position in the application of artificial intelligence technologies and the energy transition process. To this end, future international cooperation and policy design should focus on advancing the following aspects: first, strengthening the development of data governance frameworks adapted to the national conditions of developing countries; second, emphasizing the cultivation of localized technological research and development capabilities and talent training systems; third, promoting the global sharing of open-source toolkits, standardized benchmarks, and knowledge achievements. These measures aim to ensure that artificial intelligence technologies genuinely serve a fair and inclusive global energy transition process, rather than exacerbating the existing global digital divide.

6. Conclusion

6.1 Main Findings and Practical Implications

AIThe deep integration of artificial intelligence and new energy is systematically reshaping the foundational architecture and operational paradigms of energy systems. Examined from a strategic perspective, the top-level national design has established a clear roadmap and phased objectives for the integrated development of "Artificial Intelligence + Energy." From an application perspective, a number of successful cases with demonstrative effects have emerged in key areas such as power forecasting, intelligent operation and maintenance, grid dispatch, energy storage optimization, and electricity trading. Analyzed from a challenges perspective, issues including technological reliability, data barriers, information security, structural talent shortages, and computing power energy consumption still require systematic resolution.

Looking ahead, with continuous breakthroughs in trustworthy AI technologies, the deep integration of digital twins and large models, and the ongoing refinement of computing-power synergy mechanisms, energy systems are expected to progressively realize the strategic vision of integrated "source-grid-load-storage" coordination, intelligent carbon-energy nexus management, and ecosystem-based operation. Throughout this evolutionary process, technology developers and suppliers must deeply understand the intrinsic mechanisms of energy industry operations and effectively translate AI technological capabilities into quantifiable and verifiable application value. Only by doing so can they play a critically supportive role in the historical process of the energy revolution. Ultimately, artificial intelligence will develop into a foundational infrastructure technology—much like electricity itself—permeating every facet of energy systems and providing the core driving force for building cleaner, more efficient, and safer new-type energy systems.

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