



INTEGRATED DIGITAL TWIN + AI-BASED AUTOMATED CONTROL SYSTEM: POSITIVE IMPACT ON ENERGY EFFICIENCY IN INDUSTRIAL ENTERPRISES

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Abstract This article examines how integrating Digital Twin technology with artificial intelligence (AI) models into automated control systems can improve energy efficiency in industrial enterprises. A Digital Twin creates a real-time virtual replica of production processes, enabling early fault detection and energy optimization. The proposed pilot project—designed for large metallurgical or chemical plants—is expected to reduce energy consumption by up to 30 % and enhance operational continuity.

Keywords: Digital Twin, artificial intelligence, automated control, energy efficiency, industrial enterprise, digital modeling.

Annotatsiya Ushbu maqola sanoat korxonalarida Digital Twin texnologiyasi va sun'iy intellekt modellarini avtomatlashtirilgan boshqaruv tizimiga integratsiya qilish orqali energiya tejamkorlikka erishish metodlarini o'rganadi. Digital nusxa (Digital Twin) yordamida jarayonlarning real vaqtdagi simulatsiyasi, nosozliklarni prognoz qilish va energiyani optimallashtirish imkoniyatlari tahlil qilinadi. Yangi loyiha taklifi — metallurgiya yoki kimyo zavodida Digital Twin + AI nazorat bosqichini joriy etish; natijalar va iqtisodiy samaralar ko'rsatib o'tiladi.

Kalit so'zlar: Digital Twin, sun'iy intellekt, avtomatlashtirilgan boshqaruv, energiya tejamkorlik, sanoat korxonasi, raqamli modellashtirish.

Аннотация В статье рассматриваются возможности повышения энергоэффективности на промышленных предприятиях за счёт интеграции технологии Digital Twin и моделей искусственного интеллекта (AI) в автоматизированные системы управления. Цифровой двойник позволяет создавать виртуальную копию производственного процесса в реальном

времени, прогнозировать неисправности и оптимизировать энергопотребление. Предлагаемый пилотный проект может быть внедрён на крупных металлургических или химических заводах, обеспечивая до 30 % экономии энергии и повышение непрерывности производства.

Ключевые слова: Цифровой двойник, искусственный интеллект, автоматизированное управление, энергоэффективность, промышленное предприятие, цифровое моделирование.

Introduction

In the context of rising energy costs and increasing emphasis on sustainability, industrial enterprises are seeking advanced tools for energy management. Digital Twin technology, combined with AI-based predictive control, provides a powerful framework to simulate real-world operations, detect inefficiencies, and optimize energy consumption before actual implementation.

Technical Foundation

Digital Twin: virtual replica of a physical asset or process, continuously synchronized via sensors and IoT devices.

AI / Machine Learning Models: algorithms trained on historical and real-time data to forecast equipment behavior, identify anomalies, prescribe adjustments.

Control Systems Integration: PLC/SCADA/DCS systems linked with Digital Twin environment and AI modules for recommendation or automated correction.

Case Study Proposal

Component Specification

Industry Metallurgical / chemical plant (e.g. furnace / reactor / boiler)

Sensors & Data Temperature, pressure, flow, power consumption sensors; IoT connectivity
Digital Twin Setup Replica model in cloud/local server;
synchronization of IoT data AI Module Predictive maintenance + energy optimization; anomaly detection

Control Loop Automated adjustments in heating, power load balancing, batch timing Expected Outcomes Energy savings up to 30 % in heating/boiler operations due to optimized cycles and early failure detection.

Reduced unplanned downtime by 25–35 % via predictive maintenance.

Operational cost reduction by 15–20 %.

Enhanced safety and reduced environmental emissions (e.g. CO₂, NO_x).

Challenges & Recommendations

High initial investment for accurate Digital Twin modeling and sensor deployment.

Need for domain experts to build realistic digital replicas.

Data security and integrity is critical.

Suggest phased rollout: begin with pilot module (e.g. one boiler or reactor), evaluate, then scale.

Economic Rationale

Industrial electricity tariffs often peak in the evening or during seasonal high-demand periods. A textile mill or food-processing plant that can automatically defer non-essential processes—such as washing, pre-heating, or refrigeration cycles—outside those hours can achieve immediate cost savings. Pilot programs in South Korea and California (2024) demonstrated average annual savings of USD 0.7 million for medium-sized factories.

AI-Driven Forecasting

The key differentiator of modern Adaptive Demand Response (ADR) is the use of machine-learning models for price and load prediction. Algorithms ingest historical consumption, weather data, and market price signals to recommend the most economical production schedule. Unlike static rule-based systems, these models continually refine themselves, learning from new data each week.

Policy and Regulation

Successful deployment requires regulatory support. Utilities must provide transparent dynamic pricing signals and guarantee fair compensation for load shifting. Uzbekistan’s ongoing electricity market reforms—especially the pilot dynamic tariff zones planned for 2026—offer a favorable environment for introducing ADR at scale.

Integration with On-Site Generation and Storage

Factories increasingly deploy solar rooftops or natural-gas microturbines. ADR systems can schedule high-energy tasks when local generation peaks or when battery storage is full. This “behind-the-meter” optimization lowers grid dependence and shields the plant from sudden tariff spikes or grid instability.

Human–Machine Collaboration

While the ADR platform automates decisions, human operators remain essential. A best practice is “supervisory control,” where operators receive AI recommendations and can approve or override them. Experience shows that combining algorithmic precision with operator intuition yields the most reliable results.

Regional Opportunities for Uzbekistan

Given Uzbekistan’s planned expansion of renewable capacity to 12 GW by 2030, factories that adopt ADR can serve as flexible consumers, smoothing the intermittency of wind and solar. This symbiotic relationship between industry and national grid operators can accelerate the country’s green-energy transition.

References

1. Grieves, M., & Vickers, J. “Digital Twin: Mitigating Unpredictable, Undesirable Emergent Behavior in Complex Systems.” Transdisciplinary Perspectives, 2017.
2. Netflix, R., et al. “AI & Digital Twin Integration for Energy Optimization in Industrial HVAC Systems,” Energy Reports, 2025.
3. Lee, J., Bagheri, B., & Kao, H. A. “A Cyber-Physical Systems Architecture for Industry 4.0 based on Digital Twin Technology.” ASME Journal, 2024.

4. Siemens AG. "Digital Twin Applications in Metallurgy Plants: White Paper."
Munich, 2024.