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Editorial

Trends in Artificial Intelligence for Power Grid Automation from an Academic Viewpoint

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Electric power networks are interconnected systems entrusted with transforming, transmitting, and distributing electricity from generation points to the end user. Within this architecture, electrical substations perform the intermediate function of voltage transformation and help to ensure power quality through appropriate control and protection systems. Accordingly, they require automation technologies that enable the continuous monitoring, control, and protection of the infrastructure involved in these processes. Although there are international standards for grid-automation processes—most notably IEC 61850 for communications (1)—, current advances in artificial intelligence (AI) open a window of opportunity to enhance control responses to grid fluctuations.

From an academic perspective, these processes have undergone a notable evolution over the past four decades. In the 1990s, university research groups working on AI for the power sector focused on expert systems and fuzzy logic, aiming to build computational models that codified the empirical knowledge of substation technicians and other field personnel (2). The most common applications involved fault diagnosis, substation restoration, power control, and peak-load estimation in distribution systems.

In the 2000s, neural networks regained prominence and found varied applications in automation. Within power systems, they were trained on data from substations and grids for tasks such as load forecasting, fault diagnosis, and anomalous-event classification. This shift was enabled by the growing digitization of energy-infrastructure monitoring, which provided the necessary data to train detection and prediction models. For example, according to a report published by *Renewable Energy World* in September 2001, the number of projects involving automated meter reading installations in the United States grew by 40 % between 1999 and 2000 (3).

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As of 2001, this translated into roughly 13.2 % of all meters served by AMR, with similar trends persisting throughout the decade.

Between 2010 and 2015, improvements in processing power and digital storage expanded data acquisition capabilities, increasing the volume of information available to train machine-learning models for power-sector applications. For example, in 2012, researchers at Columbia University presented a supervised learning approach to fault prediction using historical data from New York City (4). During this period, other studies focused on embedding neural networks into industrial controllers such as programmable logic controllers (PLCs), in order to enhance the on-device processing and interpretation of sensor data (5).

Building on the 2015 *Nature* article on deep learning by Yann LeCun, Yoshua Bengio, and Geoffrey Hinton (Nobel Prize in Physics, 2024) (6), researchers in the energy sector began exploring these methods in electric power grids. Notable lines of work included the optimal siting of electrical substations using aerial imagery, the training of high-capacity models for fault detection and anomalous-event classification, and intrusion detection in substation and grid communication networks.

Since 2021, and into the current decade, research on AI for the power sector has increasingly adopted hybrid models that fuse deep-learning techniques with physics-based or model-driven methods. Other lines of work combine multiple deep-learning architectures to enable real-time estimation, *e.g.*, inferring harmonic distortions from three-phase current and voltage measurements, as reported by researchers at the University of Johannesburg in 2023 (7). There has also been a marked rise in edge-computing approaches, wherein data are preprocessed locally before storage, monitoring, or cloud-level control, an evolution enabled by the broader deployment of smart meters. In the United States, the share of advanced meters rose from roughly 5 % in the late 2000s (≈4.7 % in 2007-2008) to 72.3 % in 2022, according to the Federal Energy Regulatory Commission's 2024 assessment.

AI continues to open meaningful avenues for improving automation across electric power networks by enhancing system-wide efficiency, reliability, and responsiveness. Key benefits include predictive maintenance, fault detection and diagnosis, and operations optimization, particularly at the substation level. However, widescale deployment still faces material hurdles: integration with existing—often legacy—systems, cybersecurity risks inherent to communications-connected infrastructures, and data quality and privacy constraints that affect both model training and dependable operation. These challenges create a timely opportunity for Colombian research groups in the energy sector to contribute from academia to the country's most ambitious objectives—most notably, a credible and sustained energy transition.

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