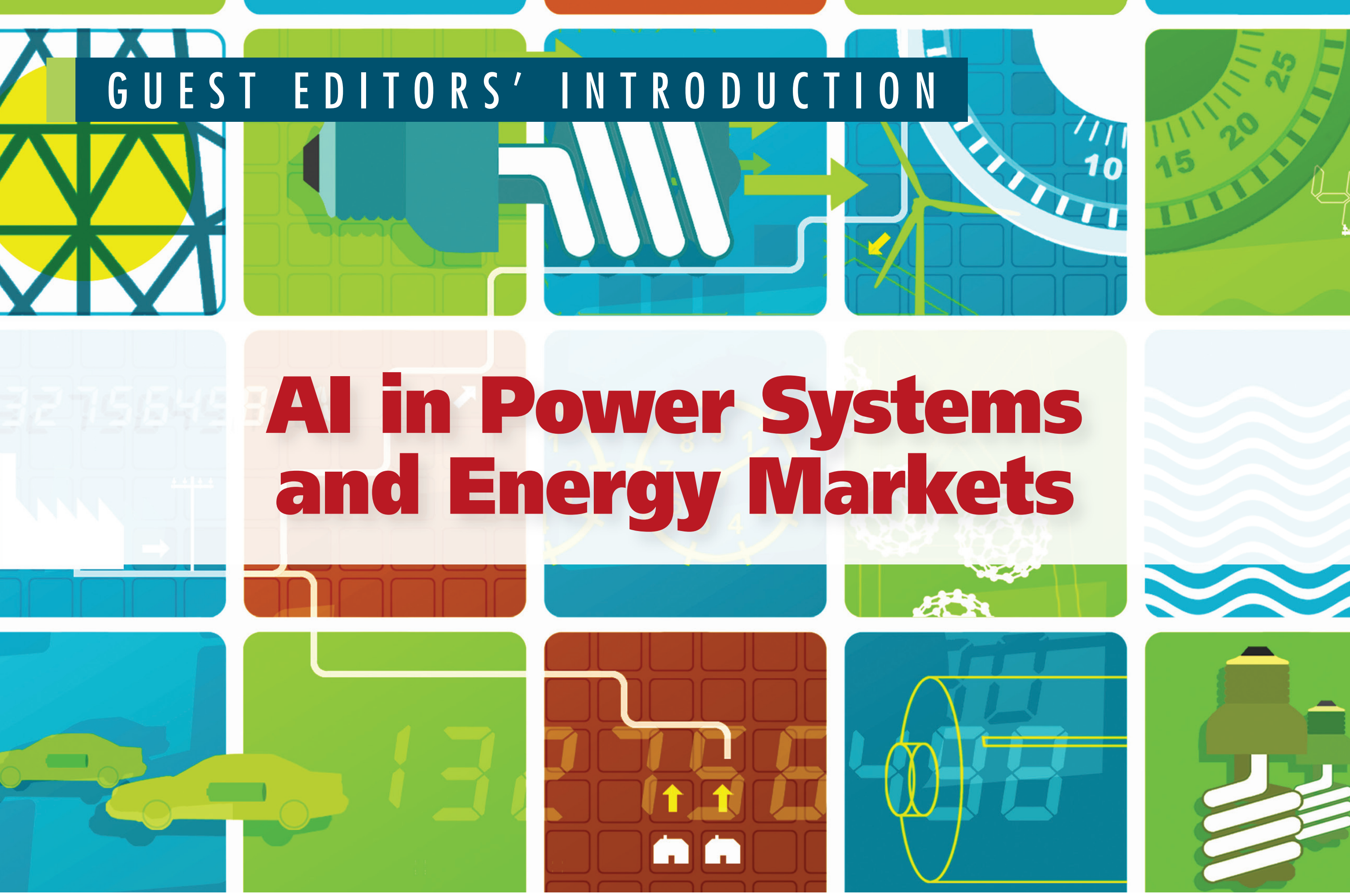

AI in Power Systems and Energy Markets

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In a world increasingly conscientious about environmental effects, power and energy systems are undergoing huge transformations. Electric energy produced from power plants is transmitted and distributed to end users through a power grid. The power industry performs the engineering design, installation, operation, and maintenance tasks to provide a high-quality, secure energy supply while accounting for its systems' abilities to withstand uncertain events, such as weather-related outages. Competitive, deregulated electricity markets and new renewable energy sources, however, have further complicated this already complex infrastructure.

Sustainable development has also been a challenge for power systems. Recently, there has been a significant increase in the installation of distributed generations, mainly based on renewable resources such as wind and solar. Integrating these new generation systems leads to more complexity. Indeed, the number of generation sources greatly increases as the grid embraces numerous smaller and distributed resources. In addition, the inherent uncertainties of wind and solar energy lead to technical challenges such as forecasting, scheduling, operation, control, and risk management.

In this special issue introductory article, we analyze the key areas in this field that can benefit most from AI and intelligent systems now and in the future.

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We also identify new opportunities for cross-fertilization between power systems and energy markets and intelligent systems researchers.

Economics and AI

Power system experts are fully aware that there is a risk of degradation with increasingly complex power systems. The power grid is a physical infrastructure with specific constraints. Although reliability is a key requirement, the complexity of power grids and the potential cascading events combining natural and human causes can lead to catastrophic failures. Several severe incidents have already occurred, such as the 14 August 2003 blackout in the US; the 4 October 2006 quasi-blackout that affected nine European countries; and the 10 November 2009 Brazilian blackout that affected 70 million people in 18 states, including the major southern cities of São Paulo and Rio de Janeiro.

Thus, practical power system engineering and energy market problems require logic reasoning, heuristic search, perception, and the ability to handle uncertainties.[1–2] This environment creates an opportunity for cross-fertilization between power systems and energy markets researchers and new developments of AI. AI and intelligent systems are potentially powerful tools to provide new solutions where other computer technologies are insufficient. Intelligent systems are natural decision-support tools for planning, operation, maintenance, market monitoring, and risk management. This new generation of technologies must combine the technical operation of the power grid with the trading activities of electricity markets.

More specifically, intelligent systems can be most fruitful in the power and energy systems domain in several key problems areas:[3]

- *Alarm processing, diagnosis, and restoration.* Expert systems and other knowledge-based systems have been used to address alarm processing, diagnosis, and restoration support at both the dispatch and control-center levels and the substation and generation-plant levels. When data and information concerning numerous events covering a large set of foreseen cases are available, an artificial neural network can be designed and trained with good results. The power industry trains control-center operators using software simulators, and some have experimented with intelligent tutoring systems.
- *Forecasting.* The level of load demand determines the amount of energy supply from power plants. Neural networks have been extensively used for forecasting tasks. They have also been used in price forecasting for electricity markets, primarily combined with fuzzy logic.
- *Security assessment.* Security assessment evaluates a power system's ability to face a set of contingencies in static and dynamic situations. Pattern recognition methods and artificial neural networks have been developed to meet these challenges.
- *Planning and scheduling.* These techniques are necessary in electrical networks and generation expansion planning as well as for several operation problems, such as unit commitment, optimal dispatch, hydro-thermal coordination, network reconfiguration, and maintenance scheduling. The techniques frequently used to solve these problems are computational intelligence and bioinspired techniques, including artificial neural networks, fuzzy systems, genetic algorithms, simulated annealing, tabu search, swarm intelligence, and ant colonies.
- *Energy markets.* While power-system engineering deals with the technical aspects of the grid, energy markets take into account the economic perspective of the power industry. Multiagent system, machine learning, data mining, and game theory techniques are used in solving problems in energy markets.

Although the connection between intelligent systems and power systems and energy market researchers is beneficial for both communities, thus far, power and energy applications have not been very visible at AI or intelligent system events or in journals. Nevertheless, the power and energy scientific community have developed various applications of computational intelligence methods. Table 1 lists the AI techniques, type of problems, and application areas in power and energy fields for the articles submitted to this special issue, which give a good sampling of the state-of-the-art work in the area.

As Table 1 shows, neural networks, reinforcement learning, genetic algorithms, fuzzy systems, particle swarm optimization, and multiagent systems are common techniques for several problem areas related to classification, forecasting, planning, optimization, and control.

Special Issue Articles

The articles selected for this special issue provide state-of-the-art information about research being conducted using AI in power systems and energy markets.

Zita Vale, Tiago Pinto, Isabel Praça, and Hugo Morais's article

Table 1. Analysis of submitted special issue articles.

AI generic areas	Number of submissions	Intelligent systems techniques*	Type of problem*	Power and energy applications
Knowledge-based systems	3	Expert systems (2), intelligent tutoring systems	Design, monitoring, training	Cogeneration power plants, transformer quality control, incident analysis in power systems control centers
Probabilistic reasoning	1	Probabilistic reasoning	Monitoring	Viscosity control in fossil fuel power plants
Incomplete information	1	Incomplete information	Forecasting	Electricity market pricing
Fuzzy systems	4	Fuzzy systems (3), Neuro-fuzzy	Diagnosis, control (2), optimization	Oscillations in interconnected systems, incident analysis in power systems control centers, minimization of voltage sag and swell metering systems, power system stability
Constraints	1	Constraint satisfaction	Control	Smart grid
Basic search	2	Local search, tabu search	Planning	Switch allocation in distribution networks, distributed network expansion planning
Evolutionary algorithms	9	Genetic algorithms (9)	Optimization (6), test, assignment, planning	General power systems, distribution systems, assigning computer resources to real-time digital simulators, market power, short-term scheduling of distributed energy resources, benefits of distributed generation owners, minimization of voltage sag and swell metering systems, distributed generation planning, vulnerability analysis in power systems
Swarm intelligence	8	Particle swarm optimization (8)	Optimization (4), planning (2), reconfiguration, dispatching, selection, classification, estimation, forecasting	Composite load model parameters, short-term load forecasting, demand response, short-term scheduling of distributed energy resources, dispatching wind farms reactive power sources, distributed network expansion planning, feeder reconfiguration in distribution systems, feature selection in nontechnical losses detection
Game theory	2	Game theory (2)	Classification (2)	Learning behavior of electricity markets players, generation reliability in power markets
Pattern matching	1	Pattern recognition	Monitoring	Reduction of power consumption
Machine learning, data mining	15	Neural networks (6), reinforcement learning (4), k-means (2), decision trees, support vector machines, neuro-fuzzy	Classification (4), forecast (3), monitoring (2), estimation (2), clustering, control, optimization, modeling	Stability assessment, transmission expansion planning, hydrocarbon development, viscosity control in fossil fuel power plants, generation reliability in power markets, short-term load forecasting, control of wind generators, analysis of overvoltages in power system restoration, nonintrusive load monitoring, power system stability, learning behavior of electricity markets players, electricity market pricing, bids in electricity markets, profits in electricity markets, incident analysis in power system control centers
Agent-based systems	4	Multiagent systems (2), agent-based simulation (2)	Modeling, forecasting, optimization, control, negotiation	Electricity markets, electricity market bids, electricity markets profits, smart grid

*The numbers in parentheses represent the number of articles using that IS technique or covering that type of problem.

"MASCEM: Electricity Markets Simulation with Strategic Agents" describes a multiagent simulator for electricity markets, MASCEM, that uses reinforcement learning to forecast bids.

"Grid Monitoring and Market Risk Management" by Yufan Guan and Mladen Kezunovic applies fuzzy systems and Petri nets to support power-system control-center operators on the economic impact of incidents.

In "A Data-Mining-Based Methodology for Transmission Expansion Planning," Judite Ferreira, Sérgio Ramos, Zita Vale, and João Soares use data mining techniques operated on data from the California state electricity market to reach important conclusions about network transmission expansion planning.

The work presented by Victoria M. Catterson, Euan M. Davidson, and Stephen D.J. McArthur, "Embedded

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Intelligence for Electrical Network Operation and Control," discusses practical applications of intelligent agents to the emerging area of the smart grid.

Lastly, Carlos Frederico M. Almeida and Nelson Kagan's article "Using Genetic Algorithms and Fuzzy Programming to Monitor Voltage Sags and Swells" combines genetic algorithms and fuzzy systems for optimization of power systems voltage control.

Future Research and Applications

When we compared the 41 articles submitted for this special issue with the article topics of the previous *IEEE Intelligent Systems* special issues in the last two years, we noted that several new fruitful AI fields are underrepresented in this special issue:

- Agents and data mining[4] are particularly interesting for the smart grid and energy markets, namely concerning agents for information mining.
- Context-awareness and smart environments[5] or ambient intelligence[6] are useful for managing control centers and energy markets.
- Group decision making and emotional computing[7] are important for tasks such as power system restoration and energy pricing.
- Intelligent monitoring of complex environments[8] is essential for cyber-physical infrastructures of power systems and smart grid; cyber security of the power grid is an excellent example.[9]
- Intelligent search and retrieval of market information, based on the Semantic Web,[10] allow a layer of competitive intelligence in energy markets and business.[11]

Based on these observations, we believe that power systems and energy markets researchers and organizations need to explore new areas of AI research. Such areas have the potential to create a knowledge-oriented business for the field and a human-level intelligence in the developed systems.[12] We also recommend that AI researchers should start focusing on the power systems and energy markets applications field. Because the costs of energy resources are increasing and environmental sustainability is crucial for modern societies, research investments in these high-impact areas will certainly increase.

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