Intelligent Systems in Power Systems and Energy Markets

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In a world increasingly conscientious about the environmental aspects, Power and Energy Systems are experiencing huge transformations in many ways. Electric energy produced from power plants is transmitted and distributed to end users through the power grid. Power industry performs the engineering design, installation, operation and maintenance tasks to provide high quality and secure energy supply taking into account the system’s abilities to withstand uncertain events such as weather related outages. Sustainable development has also been a challenge for power systems. In recent years, there is a significant increase in installation of Distributed Generations, mainly based on renewable resources such as wind and solar. The integration of these new generation systems leads to systems that are much more complex. Indeed the number of generation sources greatly increases as the grid embraces the large number of smaller and distributed resources. Uncertainties of the wind or solar energy lead to technical challenges such as forecasting, scheduling, operation, control and risk management.

Electricity markets and new renewable energy sources bring a higher level complexity through the economic dimension. The power grid is a physical infrastructure with specific constraints. Although reliability is a key requirement, complexity of the power grids and the potential cascading events combining natural and human causes can lead to catastrophic failures. Several severe incidents, including blackouts, occurred (e.g. the 14th August 2003 Blackout in USA; the 4th October 2006 quasi-blackout affecting 9 European countries; and the 10th November 2009Brazilian blackout affecting 70 million people in 18 states, including major southern cities São Paulo and Rio de Janeiro). Power system experts are fully aware that there is a risk of degradation with the increasing complexity of power systems.

Some of the tasks involved in power engineering and economics are highly complex. Practical power system engineering and energy market problems require logic reasoning, heuristic search, perception, and/or the ability to handle uncertainties [1-2]. Artificial Intelligence (AI) or intelligent systems (IS) are potentially powerful tools to provide new solutions where other computer technologies cannot. This new generation of technologies needs to combine the technical operation of the power grid with the trading activities of electricity markets. Intelligent systems are natural decision support tools for planning, operation, maintenance, market monitoring, and risk management.

Reference [3] provides an analysis of the applications of IS techniques to Power and Energy Systems. The main problems types where IS are used are the following:

- Alarm Processing, Diagnosis and Restoration - Expert systems and other knowledge-based systems have been used to address alarm processing, diagnosis and restoration support at the dispatch and control center level but also at substation and generation plant level. When data and information concerning a large number of 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 performs training of the Control Center operators using software simulators, some experiences have been gained 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, namely 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 for security assessment.
- Planning and Scheduling – These techniques are necessary in electrical networks and generation expansion planning and in several operation problems, e.g., unit commitment, optimal dispatch, hydro thermal coordination, network reconfiguration, and maintenance scheduling. The techniques frequently
used to solve these problems are computational intelligence and bio-inspired techniques, inspired in nature and animal behavior, including: artificial neural networks, fuzzy systems and genetic algorithms, simulated annealing, tabu search, swarm intelligence, and ant colony.

- Energy Markets – While power system engineering deals with the technical aspects of the grid, Energy Markets lead to an economic perspective of the power industry. Multi-Agent System, Machine Learning / Data Mining, and Game Theory techniques are used in solving problems in Energy Markets.

While the connection between IS and Power Systems and Energy Market researchers is beneficial for both IS and power system communities, power and energy applications are not very visible at AI or IS events and journals. On the other hand, the Power and Energy scientific community develops various applications of Computational Intelligence methods. Table I illustrates the AI techniques, type of problems and application areas in Power and Energy fields for the papers submitted to this special issue, a good collection of samples of the state-of-the-art work in the area.

### Table I – Analysis of Submitted Papers

<table>
<thead>
<tr>
<th>AI Areas</th>
<th>Generic Areas</th>
<th>Number of Submissions</th>
<th>IS Techniques</th>
<th>Type of Problem</th>
<th>Power and Energy Applications</th>
</tr>
</thead>
<tbody>
<tr>
<td>Probabilistic Reasoning</td>
<td>1</td>
<td>Probabilistic Reasoning</td>
<td>Monitoring</td>
<td>Viscosity Control in Fossil Fuel Power Plants</td>
<td></td>
</tr>
<tr>
<td>Incomplete Information</td>
<td>1</td>
<td>Incomplete Information</td>
<td>Forecasting</td>
<td>Electricity Market Pricing</td>
<td></td>
</tr>
<tr>
<td>Fuzzy Systems</td>
<td>4</td>
<td>Fuzzy Systems (3), Neuro-Fuzzy</td>
<td>Diagnosis, Control (2), Optimization</td>
<td>Oscillations in Interconnected systems; Incident Analysis in Power Systems Control Centers; Minimization of Voltage Sag/Swells Metering Systems; Stability of Power Systems</td>
<td></td>
</tr>
<tr>
<td>Constraints</td>
<td>1</td>
<td>Constraint Satisfaction</td>
<td>Control</td>
<td>Smart Grid</td>
<td></td>
</tr>
<tr>
<td>Basic Search</td>
<td>2</td>
<td>Local Search, Tabu Search</td>
<td>Planning</td>
<td>Switch Allocation in Distribution Networks, Distributed Network Expansion Planning</td>
<td></td>
</tr>
<tr>
<td>Swarm Intelligence</td>
<td>8</td>
<td>Particle Swarm Optimization (8)</td>
<td>Optimization (4), Planning(2), Reconfiguration, Dispatching, Selection, Classification, Estimation, Forecasting</td>
<td>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 Non-Technical Losses Detection</td>
<td></td>
</tr>
<tr>
<td>Game Theory</td>
<td>2</td>
<td>Game Theory (2)</td>
<td>Classification (2)</td>
<td>Learning Behavior of Electricity Markets Players, Generation Reliability in Power Markets</td>
<td></td>
</tr>
<tr>
<td>Pattern Matching</td>
<td>1</td>
<td>Pattern Recognition</td>
<td>Monitoring</td>
<td>Reduction of Power Consumption</td>
<td></td>
</tr>
<tr>
<td>Machine Learning, Data Mining</td>
<td>15</td>
<td>Neural Networks (6), Reinforcement Learning (4), k-means (2), Decision Trees, Support Vector Machines, Neuro-Fuzzy</td>
<td>Classification (4), Forecast (3), Monitoring (2), Estimation (2), Clustering, Control, Optimization, Modelling</td>
<td>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</td>
<td></td>
</tr>
</tbody>
</table>
As shown in Table 1, Neural Networks, Reinforcement Learning, Genetic Algorithms, Fuzzy Systems, Particle Swarm Optimization, and Multi-Agent Systems are the common techniques for several problem areas related to classification, forecasting, planning, optimization, and control. When we compare the 41 papers submitted for this special issue with papers of the topics of the special issues proposed by IEEE Intelligent Systems in the last 2 years, several new fruitful AI applications to Power Systems and Energy Markets are not represented in this special issue. Some examples are:

- Agents and Data Mining [4], concerning agents for information mining, particularly interesting for the Smart Grid and Energy Markets;
- Context-Awareness and Smart Environments [5] or Ambient Intelligence [6], useful for management of Control Centers and Energy Markets;
- Group Decision Making and Emotional Computing [7], important for tasks such as Power System Restoration and Energy Pricing;
- Intelligent Monitoring of Complex Environments [8], essential for Cyber-Physical infrastructures of Power Systems and Smart Grid; cyber security of the power grid is an excellent example [9];

Based on the above observations, we recommend that:

- Power Systems and Energy Markets researchers and organizations explore new AI areas of research, since these new areas have the potential to create a knowledge-oriented business for the field and a human-level intelligence in the developed systems [12];
- AI researchers start to focus on Power Systems and Energy Markets applications field, since as the Energy resources increase the cost and Environment and Sustainability are crucial for the society, research investments in these fields will increase. Applications to Power and Energy systems are high-impact areas involving complex problems.

In the introductory article of this special issue by the Guest Editors, we analyze the AI techniques, types of problems, and application areas of all papers submitted to this special issue. We also identify an opportunity for the cross-fertilization between Power Systems and Energy Markets researchers and new developments of AI. The papers selected for this special issue will provide the state-of-the-art information about research being conducted using AI in Power Systems and Energy Markets. The work presented by Vale, Pinto, Praça, and Morais describes MASCEM, a multi-agent simulator for Electricity Markets, using reinforcement learning for forecasting bids. The paper by Guan, and Kezunovic applies Fuzzy Systems and Petri Nets to support power systems control center operators on the economic impact of incidents. Ferreira, Ramos, Vale, and Santos use Data Mining techniques operated on the data of the California state Electricity Market for achieving important conclusions about the Network Transmission Expansion Planning. The work presented by Catterson, Davidson, and McArthur discusses practical applications of AI technology, namely Intelligent Agents, to the emerging area of Smart Grid. The work of Almeida and Kagan combines Genetic Algorithms and Fuzzy Systems for optimization of power systems voltage control.
References

4. L. Cao, V. Gorodetsky, and P. Mitkas; Agents and Data Mining; IEEE Intelligent Systems; vol. 24, n.3, pp 14-15; 2009.