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Dissertation Title: AI-Based Decision Systems for Operational Planning and Real-Time Power Grid Management

Date: 13/07/2026 14:00

Location: University of Porto | Faculty of Engineering | Department of Electrical and Computer

Higher Education Institution: University of Porto

Abstract or Public Summary: The global transition toward decarbonized power systems introduces significant challenges for grid operation and market management, driven by increasing renewable energy penetration and widespread electrification. These developments reduce system capacity margins and amplify uncertainties in load and renewable generation forecasts, demanding novel approaches to operational flexibility, decision-making, and explainability. This thesis addresses these challenges through a series of complementary contributions that integrate predictive algorithms, hybrid artificial intelligence, and interpretable decision-support frameworks for modern power systems. The first contribution proposes a predictive algorithm for the procurement of grid flexibility by the system operator (SO), combining SO-controlled flexible assets with active and reactive power short-term flexibility markets. By reducing the cognitive load on human operators and implementing a “time-to-decide” method, the framework allows operators to balance risk, cost, and operational stakes when deciding whether to book flexibility immediately or wait for updated forecasts. Numerical results on a public medium-voltage grid (Oberrhein) show that this approach improves a cost-loss performance indicator by up to 22% compared to immediate flexibility booking strategies. The second contribution introduces a hybrid AI framework for power grid topology control, combining Genetic Network Programming (GNP), reinforcement learning, and decision trees. A novel variant of GNP is developed to evolve decision-making rules from operational data, providing transparent and traceable reasoning while managing N-1 contingencies in real-time grid operations. The method outperforms both a baseline expert system and a state-of-the-art deep reinforcement learning agent on the IEEE 118-bus system, achieving up to a 28% improvement in a key performance metric from the Learning to Run a Power Network (L2RPN) competition. The third contribution addresses the interpretability gap in Alternate Current Optimal Power Flow (AC-OPF) redispatch solutions. An interpretable and adaptive framework is proposed that combines post-optimal physical analysis with a multi-agent large language model architecture to generate concise, operator-oriented explanations of AC-OPF redispatch decisions. The proposed framework uses physically grounded information, including dual variables, linearized sensitivities, and line outage distribution factors, to support counterfactual reasoning about constraint drivers, feasible redispatch alternatives, and their approximate economic and security implications. A reflective multi-agent loop composed of an Actor, Critic, Distiller, and Refiner iteratively improves the explanation process by extracting compact operational rules and integrating them into the Actor prompt through a sliding-window refinement mechanism. Evaluation on the test system shows that the evolved framework produces explanations that are physically consistent, numerically defensible, causally coherent, and highly readable, while also generalizing effectively to unseen operating snapshots. With low computational overhead, the proposed approach enhances situational awareness by translating AC-OPF outputs into transparent and operationally meaningful redispatch explanations. Together, these contributions advance the state-of-the-art in flexible, AI-driven, and interpretable power system operation. By integrating predictive flexibility procurement, hybrid AI-based topology control, and interpretable AC-OPF reasoning, this thesis provides tools that improve operational efficiency, support human-in-the-loop decision-making, and enhance trust in automated grid management under uncertainty.

Doctoral Programme: Doctoral Program in Electrical and Computer Engineering

Research Centre: CPES

Principal Supervisor at INESC TEC: Ricardo Jorge Bessa

Scientific Domain: Artificial Intelligence; Computer Science and Engineering; Power and Energy Systems

Keywords: power system operation; decision-making; predictive management; real-time management; artificial intelligence