

Project Title: Physics-Grounded RAG-Enhanced LLM Agents for Reliable Power-System Simulation, Optimization, and Security Assessment

Project Type: Master's Thesis or Semester Project

Project Description: This master thesis aims to develop an agentic AI framework that can autonomously perform power-system studies using a combination of large language models (LLMs), retrieval-augmented generation (RAG), power-system simulation tools, and physics-based validation. The proposed system will allow a user to ask natural-language questions such as:

- “Run optimal power flow on IEEE 30-bus and identify constraint violations.”
- “Perform N-1 contingency analysis and rank the most critical outages.”
- “Explain why bus voltages are below limits and suggest corrective actions.”

The agent will interpret the request, select the appropriate analysis workflow, execute the required simulation, validate the results using deterministic engineering rules, and generate a technically grounded explanation. The project builds on recent research showing that LLMs can assist power-system simulations, but also that direct LLM use suffers from limited domain knowledge, reasoning errors, and imprecise handling of simulation parameters unless combined with RAG, tool execution, and feedback mechanisms.

The thesis will use a simulation backend such as pandapower, which supports power-flow analysis, optimal power flow, state estimation, short-circuit calculation, topology search, and power-system modeling in Python. For security assessment, the system will implement or use N-1 contingency analysis, where lines or transformers are switched off one at a time and post-contingency voltage and loading limits are evaluated.

Key tasks during the project:

- **Natural-language task understanding:** Convert user queries into structured tasks such as power flow, OPF, or contingency analysis.
- **Tool-based simulation execution:** Connect the agent to deterministic power-system tools for power flow, OPF, and N-1 security assessment.

- **RAG-based domain grounding:** Build a knowledge base containing power-system rules, voltage limits, OPF concepts, contingency-analysis principles, and simulator documentation.
- **Physics validation:** Validate simulation outputs using engineering constraints such as voltage limits, line-loading limits, generator limits, convergence status, and OPF feasibility.
- **Explainable decision support:** Generate final reports explaining violations, ranking critical contingencies, and suggesting corrective actions.
- **Benchmark evaluation:** Compare different configurations: direct LLM, LLM with tools, LLM with RAG, and LLM with RAG plus physics validation.

Useful skills software:

- The student should understand: Power-flow, AC power flow,
- Python programming: pandas / NumPy, pandapower or MATPOWER
- Local LLM deployment with Ollama or similar tools.
- Experience with RAG is plus.

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Reference:

- [1]. X-GridAgent. A hierarchical LLM-powered agentic AI system for smart-grid analysis, including power flow, OPF, contingency analysis, short-circuit calculation, and topology search.
- [2]. GridMind: LLMs-Powered Agents for Power System Analysis and Operations. This work is directly related to LLM agents for AC OPF and contingency analysis.