



Harvard John A. Paulson
School of Engineering
and Applied Sciences

ERCOT Technology and Security Committee Meeting

A Roadmap Towards Agentic Intelligence in Power Systems

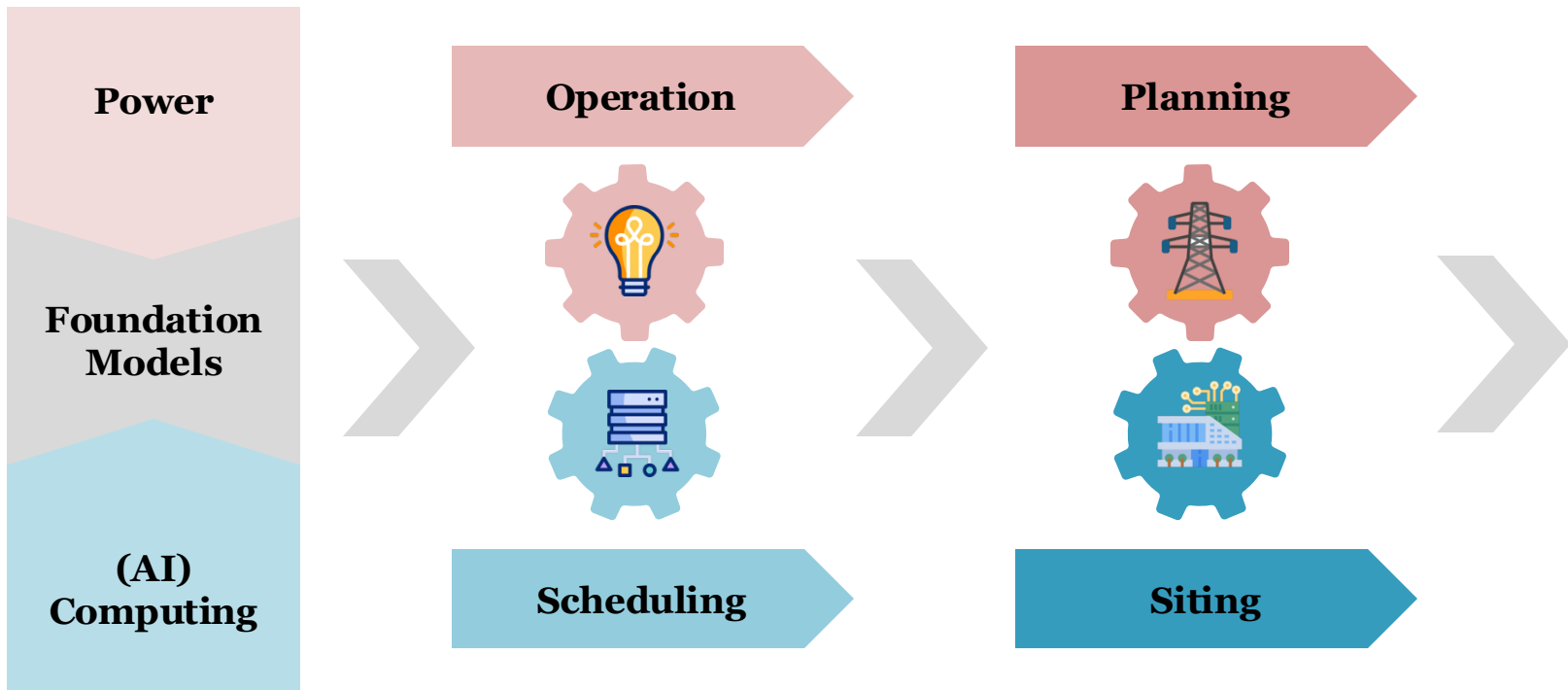
Le Xie, Fellow of IEEE

Gordon McKay Professor of Electrical Engineering

Harvard John A. Paulson School of Engineering and Applied Sciences

12/08/2025

Interplay Relation: Foundation Models



Le Xie, Qian Zhang, et al, "Crucial Role of Foundation Models in Enhancing the Interaction of AI and Power Systems", IEEE Energy Sustainability Magazine, 2025, invited paper.



The Challenge of Power for AI/Computing

Operation

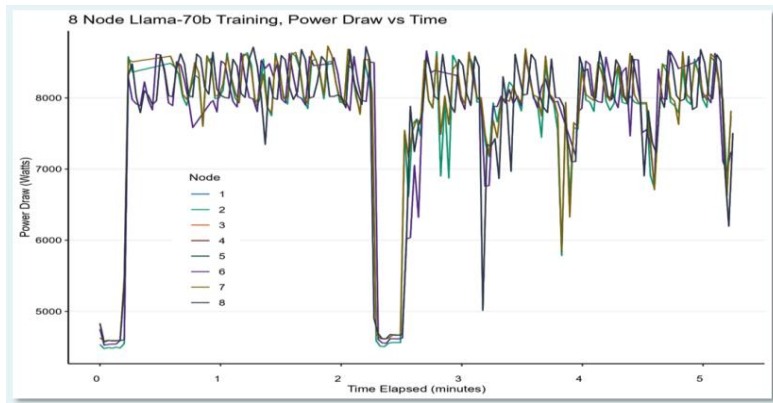
Intrinsic Physical Dynamic
during AI Training/Inference



Neither is Fully
Understood

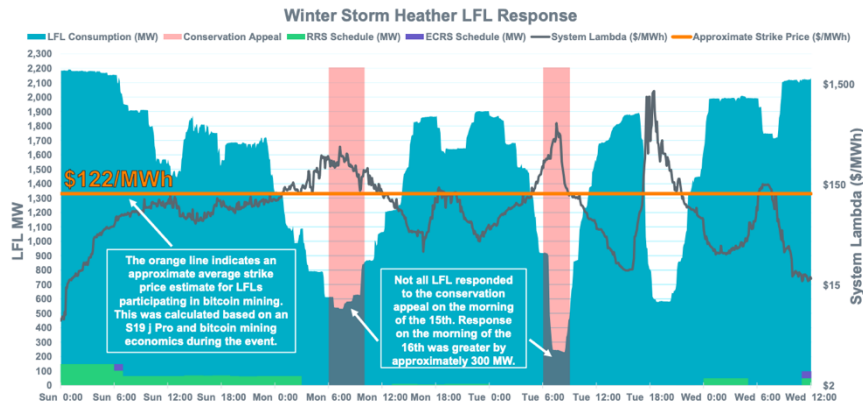


Extrinsic Market Behavior in
Electricity Market



Node-level power demand
during Llama-70B training
across 8 nodes at Metal Cloud

Source: Lawrence Berkeley National Laboratory



Large Load's Response to
Winter Storm Heather
(January, 2024)

Source: ERCOT



The Challenge of Power for AI/Computing

Planning

Increasing Large Load
Interconnection Request

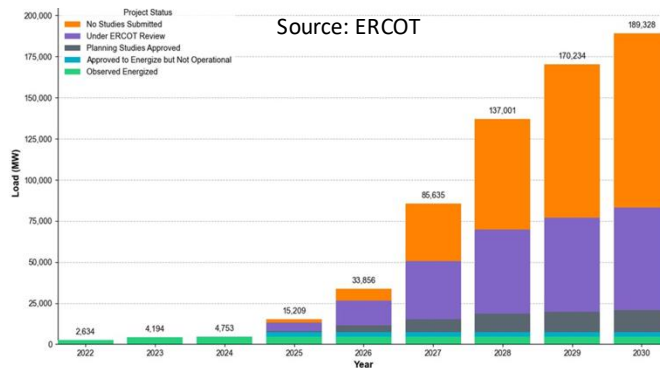


**Transmission is also
Bottleneck**



Increasing Generation
Interconnection Request

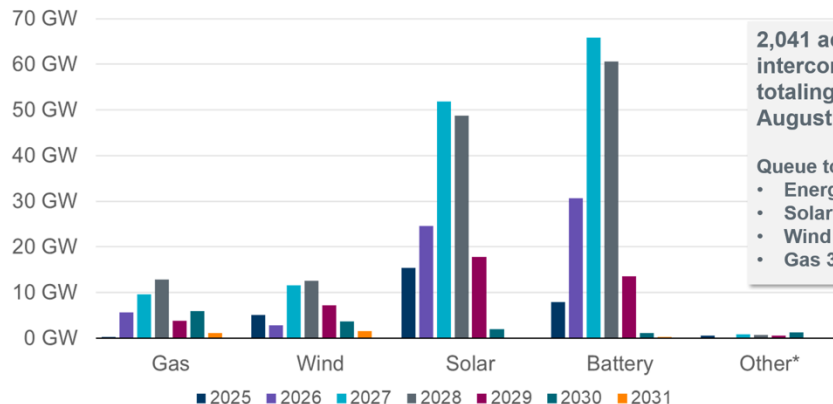
Large Load Interconnection Queue as of September 2, 2025



- ERCOT is tracking 189GW of large load compared to 56GW in Sep 2024.
- 70% of this load are data centers.

Generation Interconnection Requests

Source: ERCOT



2,041 active generation interconnection requests totaling 428,183 MW as of August 31, 2025.

Queue totals:

- Energy storage 179,838 MW
- Solar 160,192 MW
- Wind 44,649 MW
- Gas 39,403 MW



Gridcare thinks more than 100 GW of data center capacity is hiding in the grid

<https://techcrunch.com/2025/05/27/gridcare-thinks-more-than-100-gw-of-data-center-capacity-is-hiding-in-the-grid/>

Tim De Chant • 5:00 AM PDT • May 27, 2025

PJM, Google partner to speed grid interconnection using AI

The initiative aims to integrate dozens of PJM interconnection-related databases and tools into a unified model of PJM's network, helping to bring power supplies online faster.

Published April 10, 2025

<https://www.utilitydive.com/news/pjm-google-tapestry-grid-interconnection-ai/744982/>

ELECTRICITY MARKETS

OATI Launches Generative AI Platform Pilot for Power Grid Operations with CAISO

July 16, 2025 Paul Ciampoli https://www.publicpower.org/periodical/article/oat-i-launches-generative-ai-platform-pilot-power-grid-operations-with-caiso?utm_source=chatgpt.com

NEWS | 24 July 2025

<https://www.nature.com/articles/d41586-025-02343-x>

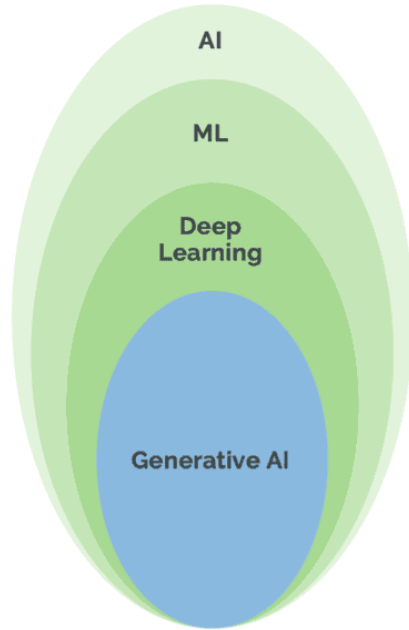
DeepMind and OpenAI models solve maths problems at level of top students

For the first time, large language models performed on a par with gold medallists in the International Mathematical Olympiad.

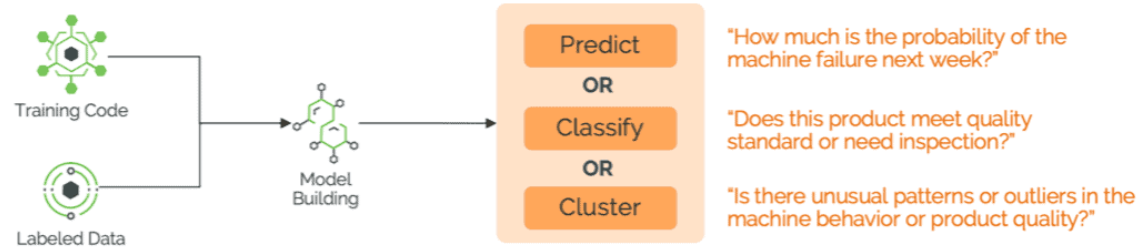
By [Davide Castelvecchi](#)

The challenges created by AI may be addressed by the super intelligence emerging from foundation models

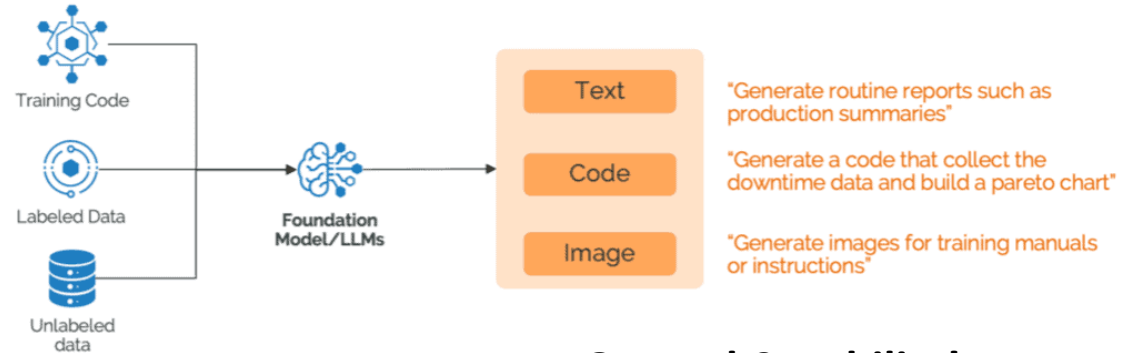
What is Generative AI/Foundation Model/Large Language Model



Classical Supervised & Unsupervised Learning



Gen AI Supervised, Semi-Supervised & Unsupervised Learning

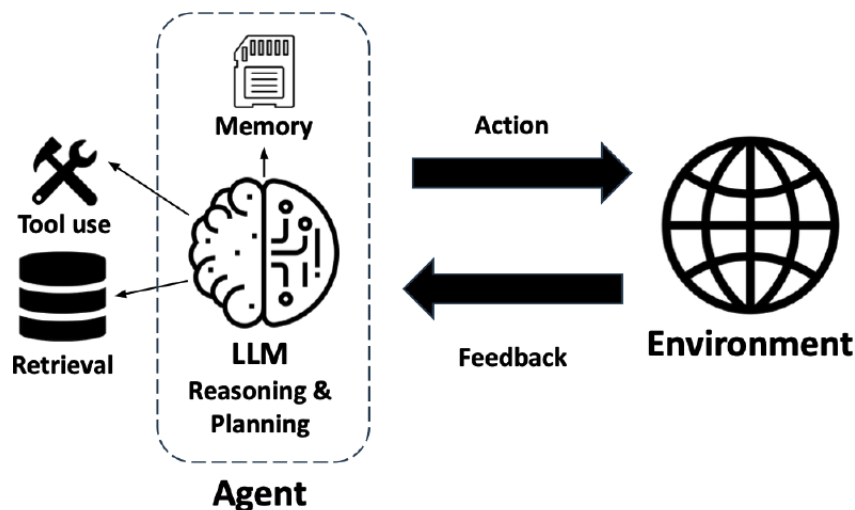


General Capability!



What is Agentic AI or AI Agent

- An AI agent is a software system that autonomously perceives its environment, makes decisions, and takes actions to accomplish complex, multi-step tasks while continuously learning and improving itself.
- How to design AI Agent: **Enabling LLMs to interact with the environment.**



- Solving real-world tasks typically involves a **trial-and-error** process
- Leveraging **external tools** and retrieving from **external knowledge** expand LLM's capabilities
- Key Elements in Agent Workflow
 - LLM Models: Reasoning, Planning, Multimodality
 - Memory and Storage
 - External Tools and Knowledge
 - Feedback System and Human in the Loop



Some Applications of AI Agent

➤ General

Designer

<https://gamma.app/>

GAMMA

Software Engineer

<https://devin.ai/>



Video Editor

<https://pippit.capcut.com/>



Voice Cloning

<https://elevenlabs.io/>

ElevenLabs

➤ Domain-specific

Government Contracting

<https://www.sweetspot.so/>



Law

<https://www.harvey.ai/>



Healthcare

<https://www.keragon.com/>



Scientific Experiment

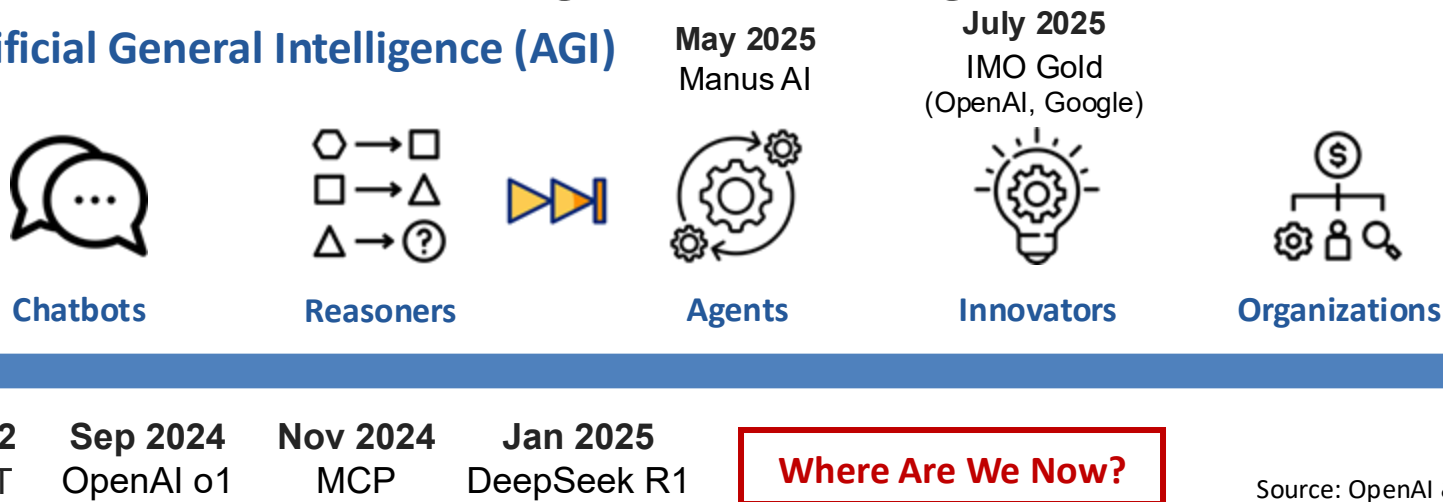
<https://www.dotmatics.com/>

Dotmatics

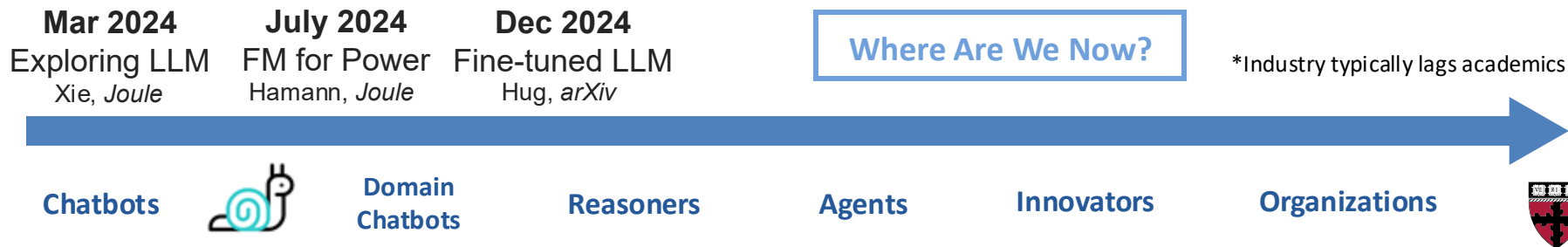


Toward AGI: The Role of Agentic Intelligence

Toward Artificial General Intelligence (AGI)



Toward AGI in Power Sector



Agentic AI: Different from Previous AI Trends

Previous AI Adoption Challenge

- **Academic: Generalization in a Complex Environment**

Power systems are governed by dynamic, non-stationary factors, like weather, human behavior, topology changes, and contingencies, that defy the independent and identically distributed (*iid*) data often assumed in learning methods.

- **Industry: Data, Security, and Cost**

In the power industry, previous AI adoption faces challenges like limited access to clean, shareable data, cybersecurity concerns, and the need for explainable, standards-compliant models. Costs for training from scratch also remain a barrier.

LLM-powered Agentic AI

- **Lower Data Needs:** Modern LLMs require only light fine-tuning or RAG to adapt to power systems—no massive datasets or full retraining needed.

- **Safer, Smarter Agents:** AI agents can use *trusted tools* like PSS®E or PowerWorld under human guidance, ensuring safer and more reliable outcomes.




- **Human-in-the-Loop Productivity:** Agentic AI acts as a co-pilot—automating routine tasks and boosting speed and accuracy while keeping engineers in control.

Driven by recent advancements in LLMs, Agentic AI addresses above challenges

indirectly but effectively



A Roadmap Towards Agentic Intelligence in Power Systems

Layer	Technology Components	Domain Expertise Needed
 Agentic Workflow orchestrating tasks and human-machine collaboration	Cloud/Local Storage, Server Orchestration, Human-in-the-loop System, Cyber Security	Organizational Insight Deep understanding of organization's structure, workflow processes, and decision hierarchies
 Agent-Tool Integration connecting LLMs to external power domain tools	MCP and API Integration, Streaming /Batch Data Integration, Error Recovery	Tool and Software Expertise Familiarity with power system engineering software (e.g., PSS®E, PowerWorld, PSCAD) and their functionalities
 Foundation Models power-specialized knowledge and reasoning engine	RAG, Fine-tuned LLMs, Full Domain-Specific FMs, Benchmarking	Power Sector Understanding Knowing physical and economical basic of energy systems, regulatory, industry standards, and legal frameworks

Enable Scalability



Power Agent

Speed Up Deployment

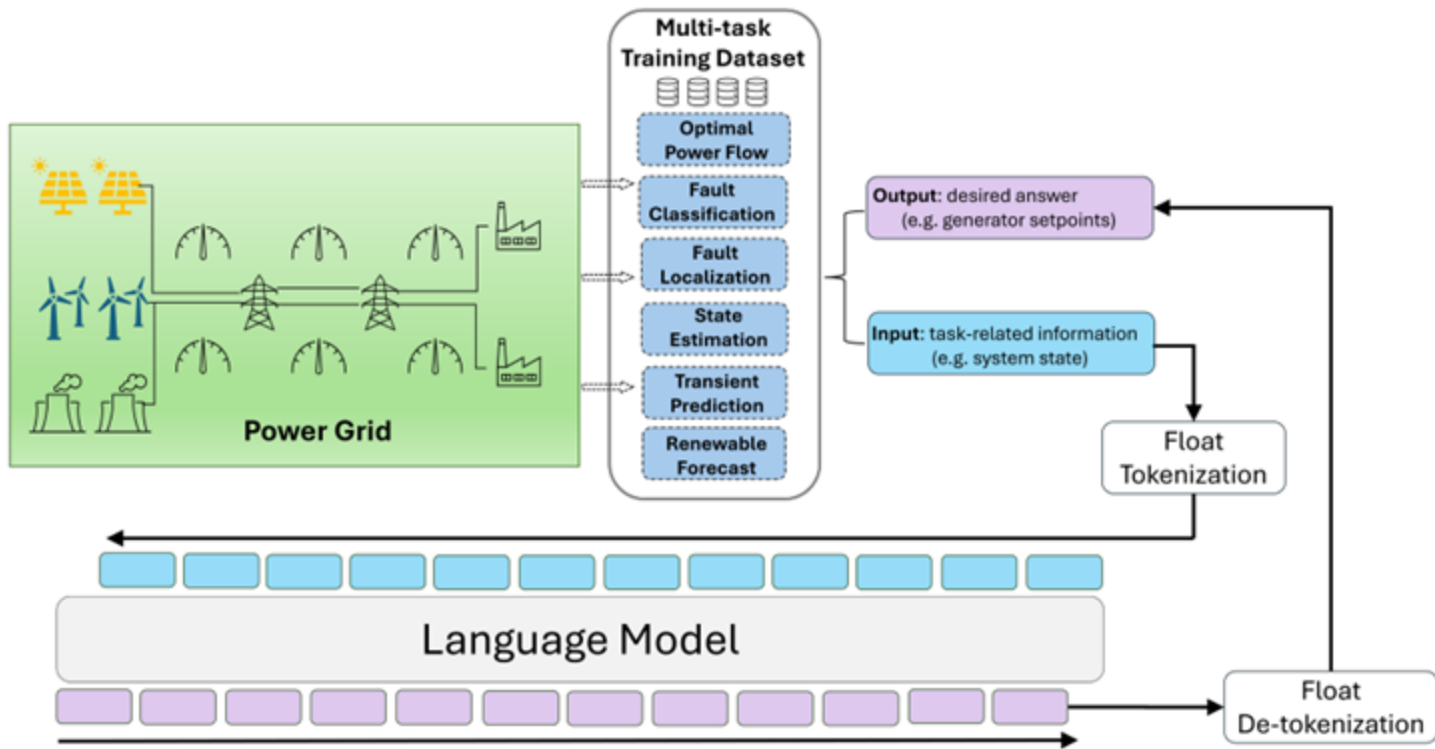


PowerWF + PowerMCP + PowerFM

Qian Zhang, Le Xie. "PowerAgent: A Roadmap Towards Agentic Intelligence in Power Systems", IEEE Power and Energy Magazine, 2025



PowerAgent Demo: *Open-source Dataset for Fine-tuning FMs*



Liu, Xie, et. al. "Unlocking Multi-Task Electric Energy System Intelligence: Data Scaling Laws and Performance with Limited Fine-Tuning," Working Paper (under review), 2025

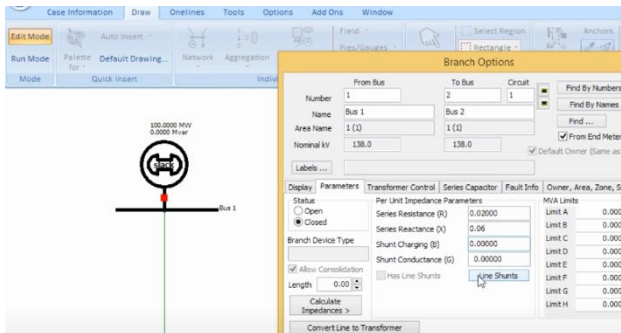


PowerAgent Demo: *Next-generation Software Interface*

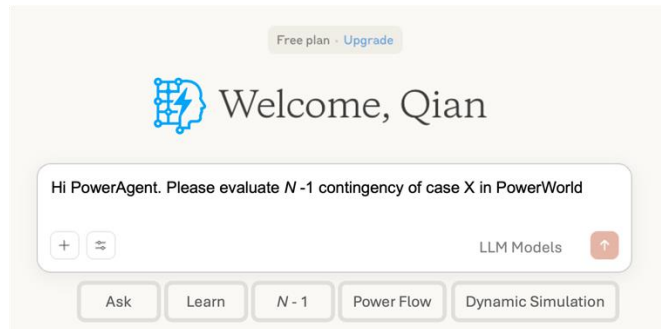
In these tasks, you'll see how PowerAgent adapts to **your preferred software environment** and **reporting format** — whether you're using *PowerWorld*, *Pandapower*, or any other trusted tool.



Choose your trusted platform.
Choose your preferred output format.
Let *PowerAgent* handle the rest.



Software as a Tool



Software as an Outcome



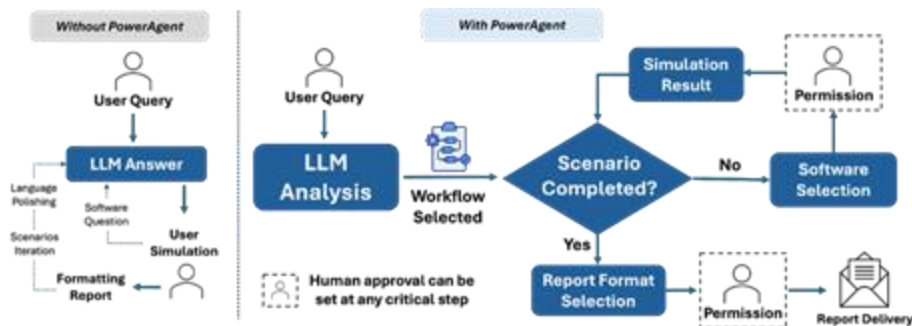
PowerAgent Demo: *Agentic Workflow for Complex Tasks*

- Example: Evaluate the potential impact for Data Center interconnection on:

- Transmission line congestions
- Voltage violations
- $N-1$ Contingency, etc

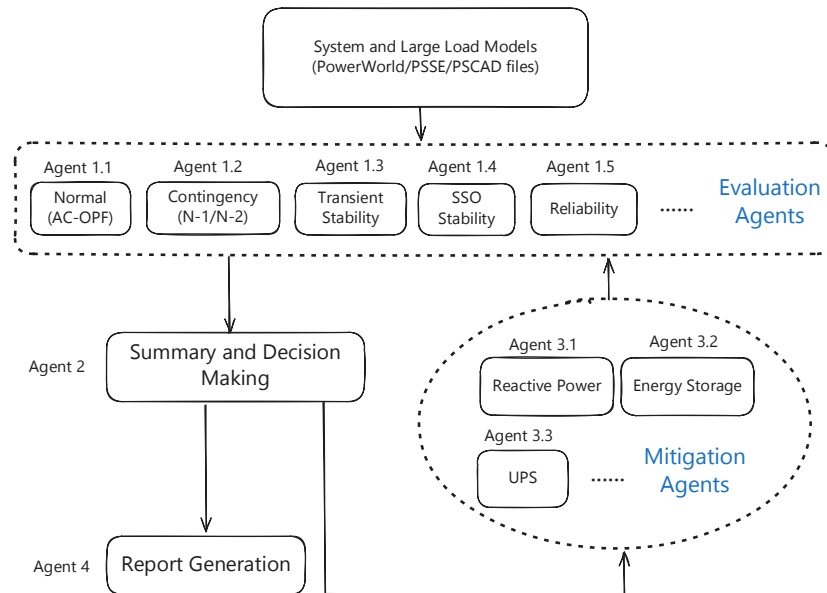
- Provide suggestions to mitigate identified issues

- Human in the Loop is allowed



The Workflow Overview

- Enable **collaboration** among domain-specific agents to **exchange feedback** and determine the **optimal mitigation** strategies



Example Agent-Orchestrated Process for Grid Impact Studies



<https://youtu.be/LxF8RqsNf04>

Check More PowerAgent Demos and Join Us

<https://power-agent.github.io/>

Datacenter Siting Assistant

Datacenter Siting Assistant: Solvtra is a tool leverages RAG by incorporating datacenter-specific data, including local regulations, environmental reports, and infrastructure details.

Input

Test Model
GPT-4o

I am looking for a datacenter location with the following requirements:

- Location: Texas
- Land budget: Maximum \$600,000 per acre
- Electricity cost: Maximum \$0.05 per kWh

Output without RAG*

Here's a strategic recommendation for a Texas datacenter location that matches requirements:
Central Texas – Temple / Waco Area. Why it fits your criteria: Central Texas typically offers commercial/industrial land well under \$600,000 per acre, often in the \$100K–\$300K range
Alternative (if you seek ultra-low power costs):
West Texas (e.g., near Abilene or Sweetwater):

*without deep research

Output with RAG**

Here are the best datacenter locations in Texas that meet your criteria:
Datacenter A (Dallas, TX), Location: (32.7355, -96.8039), **Land Price:** \$300-500K /acre, **Electricity Cost:** \$0.05-0.08/kWh, **Notes:** Adaptive data center with patented cooling technology, **Map URL:** Datacenter A MAP
Datacenter B (Dallas, TX), Location: (32.7831, -96.8067), **Land Price:** \$300-500K / acre, **Electricity Cost:** \$0.05-0.08/kWh, **Notes:** Major Texas interconnection hub, **Map URL:** Datacenter B MAP

**specific information is replaced here



Power
Agent

PowerMCP Public

PowerMCP is an open-source collection of MCP servers for power system software like PowerWorld and OpenDSS. These tools enable LLMs to directly interact with power system applications, facilitating intelligent coordination, simulation, and control in the energy domain.

• Python • MIT License • 17 • 68 • 1 • 2 • Updated last week

PowerFM Public

PowerFM is an open-source repository for foundation models in the power and energy domain. It both maintains original projects and collects community-contributed open-source projects, featuring fine-tuned and domain-trained models for tasks like load forecasting, fault detection, grid simulation, and agent control.

• MIT License • 0 • 27 • 0 • 0 • Updated yesterday

PowerWF Public

PowerWorkflow is an open-source collection of agentic workflows for power system applications. These workflows enable intelligent automation and coordination of power system operations, facilitating efficient management and control in the energy domain.

• Python • MIT License • 0 • 24 • 0 • 0 • Updated on Jul 18

Qian Zhang, Le Xie. "PowerAgent: A Roadmap Towards Agentic Intelligence in Power Systems", IEEE Power and Energy Magazine, 2025



Challenges for AI Agent Deployment

- **Reasoning and planning**

LLM agents tend to make mistakes when performing complex tasks end-to-end

- **Embodiment and learning from environment feedback**

Continuous learning, self-improvement

Multimodal understanding, grounding and world models

- **Safety and privacy**

LLMs are susceptible to adversarial attacks, can emit harmful messages and leak private data

- **Human-agent interaction, ethics**

How to effectively control the LLM agent behavior, and design the interaction mode between humans and LLM agents





PAI

Power and AI Initiative
at Harvard SEAS

pai.seas.harvard.edu

- Research
- Talent Development
- Seminar and Events
- Industry Partnerships
- And More

Core Team



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Science, Harvard SEAS



Industry Partnerships Manager

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Harvard SEAS





Harvard John A. Paulson
School of Engineering
and Applied Sciences

WHERE
SCIENCE
AND
ENGINEERING
CONVERGE

Thanks!

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