

Large Foundation Models for Power Systems

Chenghao Huang*§, Siyang Li*§, Ruohong Liu*§, Hao Wang*, and Yize Chen†

*Department of Data Science and Artificial Intelligence, Monash University, Australia

†Information Hub, Hong Kong University of Science and Technology (Guangzhou), China

December 2023

CSE 551: Smart Energy in the Information Age

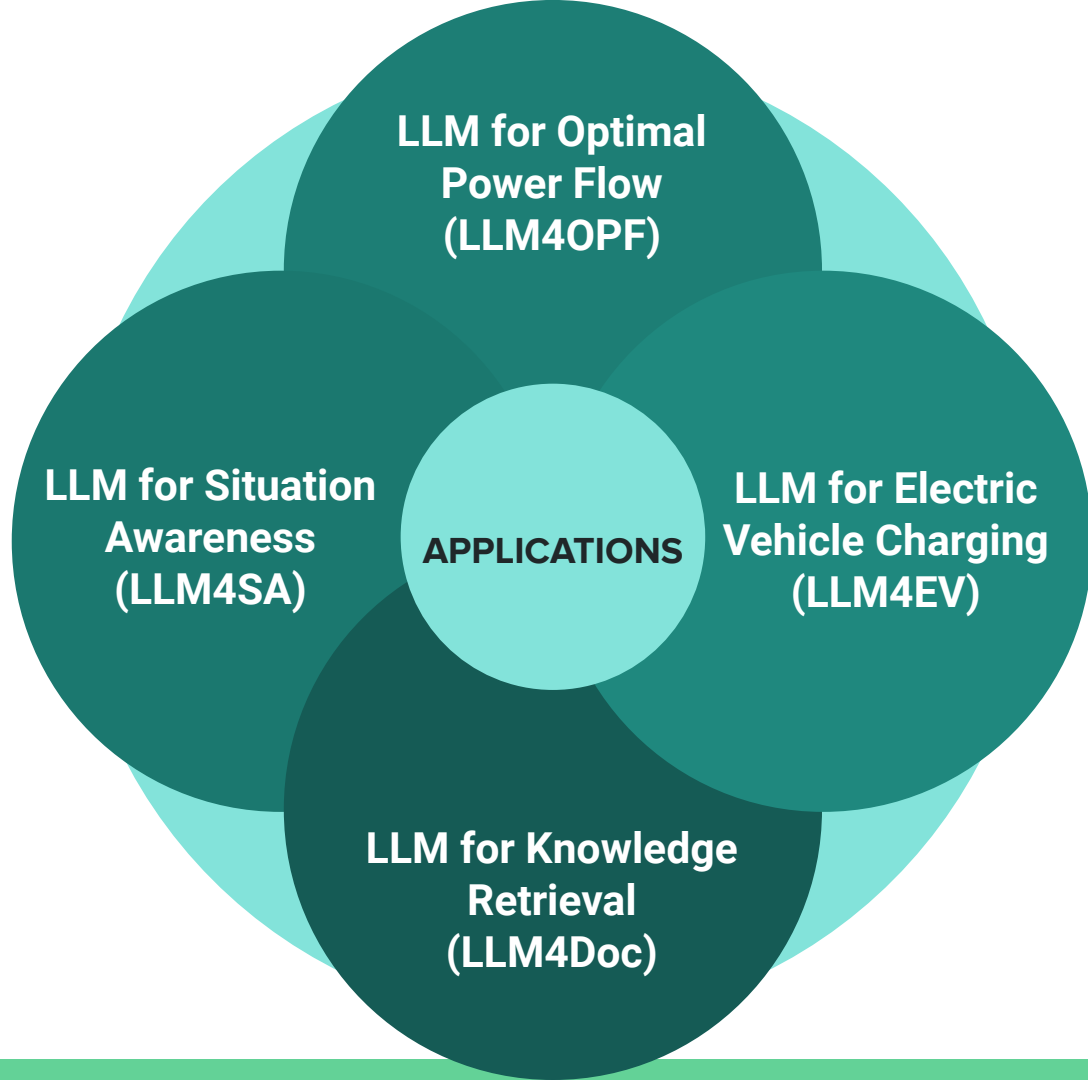
Group 11: Abhilash, Aditya, Ankith, Snigdha

Problem with ML models in power systems domain:

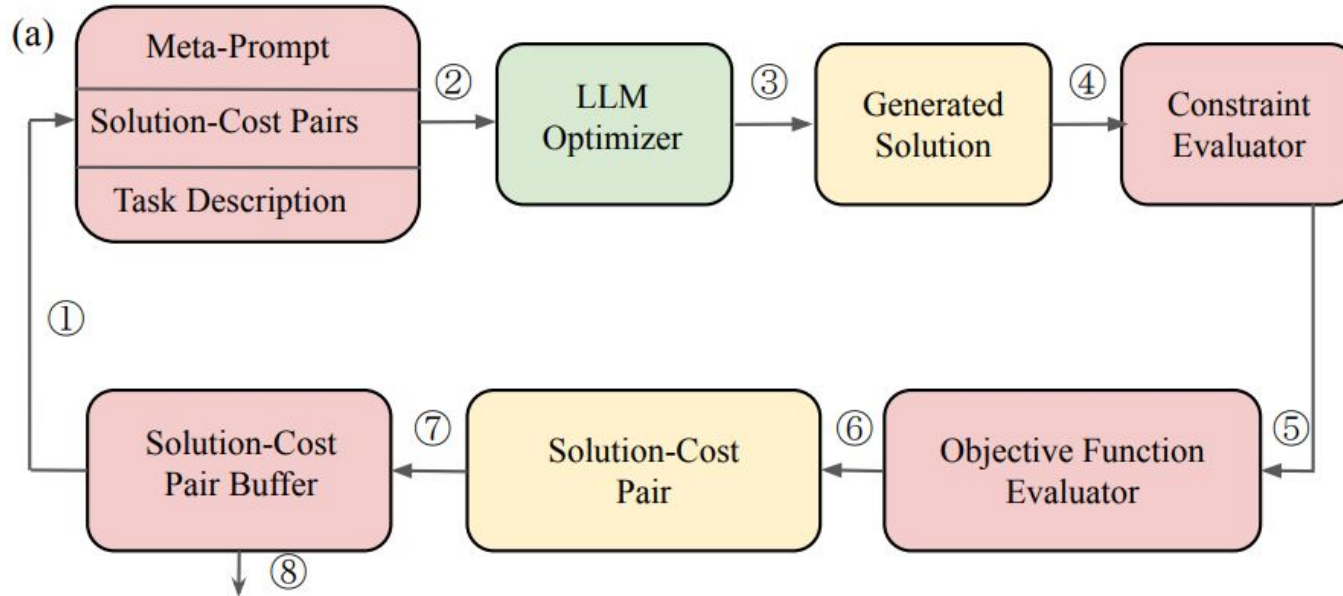
- Trained on single-source
- Domain-specific dataset
- Limited by the data collection and application scope
- Users lack domain knowledge in optimization or power systems
- Do not generate explanations

Solution: LLMs in power system domain

- LLMs exhibit generalizable capabilities across a variety of domains and tasks including reasoning, abstraction, understanding and projection
- Using pre-trained foundation models such as **GPT-4** and **GPT-4 Vision** to help engineers, policymakers, and energy users for solving challenging problems in the power and energy domain
- Effectively removes the barriers for users to interact with the power systems



1. LLM4OPF (LLM as Optimizer): Methodology



① Retrieve data. ② Input prompt. ③ Generate new solution. ④ Evaluates whether the new solution can satisfy constraints. ⑤ If yes, calculate the cost. ⑥, ⑦ Derive solution-cost pair and store. ⑧ When finish, output the solution with minimal cost.

LLM4OPF: Application

Goal: To **minimize** the quadratic power generation costs $C_i(P_i) = a_i P_i^2 + b_i P_i + c_i$, $i \in \Omega$, where P_i denotes power output of generator $i \in \Omega$. a_i , b_i and c_i denote cost coefficients.

- iteratively generates new solutions based on task description and previously generated solutions

LLM4OPF: Example

LLM4OPF

System: You need assistance in solving an optimization problem. This problem involves 5 optimization variables, namely p1, p2, p3, p4, and p5. These variables are subject to constraints defined by their minimum and maximum values: $p_{min}=[28, 90, 68, 76, 19]$ and $p_{max}=[206, 284, 189, 266, 53]$. Additionally, the sum of p1, p2, p3, p4, and p5 must be greater than or equal to 400.

Your objective is to provide values for p1, p2, p3, p4, and p5 that satisfy the constraints and minimize the optimization objective.

Below are some previous solution and their objective value pairs. The pairs are arranged in descending order based on their function values, where lower values are better.

```
Solution 1: p1, p2, p3, p4, p5 =  
          120.0, 90.0, 70.0, 85.0, 40.0\\  
Objective value 1: 141843.15\\  
Solution 2: p1, p2, p3, p4, p5 =  
          110.0, 95.0, 75.0, 85.0, 35.0\\  
Objective value 2: 137350.95\\  
...
```

Give me a new (p1, p2, p3, p4, p5) pair that is different from all pairs above, and has a function value lower than any of the above. Do not give me any explanation, the form of response must strictly follow the example:
p1, p2, p3, p4, p5 = 123.11, 80.2, 99.67, 101.52, 37

LLM4OPF: Performance Evaluation

Task	Optimizer	Cost	P_1	P_2	P_3	P_4	P_5	n
OPF	Gurobi	131455.000	102.844	90.000	76.730	77.425	53.000	-
	GPT-4	131456.090	103.000	90.000	77.000	77.000	53.000	300
OPF $L_e = 405$	Gurobi	134670.416	104.850	90.000	78.216	78.934	53.000	-
	GPT-4	134691.790	106.000	90.000	79.000	77.000	53.000	50

Where,

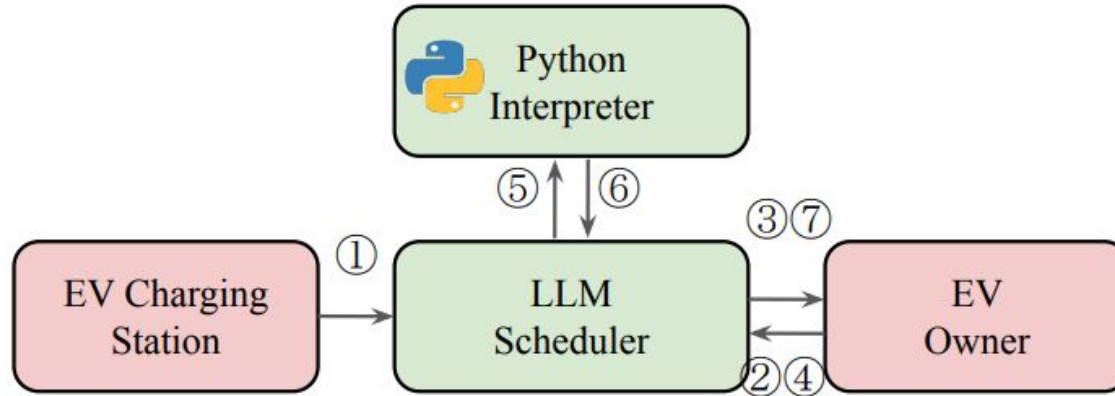
n = optimization steps,

P_i = power output of generator i

L_e = nodal load (demand)

2. LLM4EV: Methodology

(b)



- ① Describe task. ② User query. ③ Ask user to input parameters. ④ User response.
⑤ Generate code to invoke function. ⑥ Python interpreter execution. ⑦ Explain results to user.

LLM4EV: Application

Goal: To **optimize** charging power $u_j(t)$ for each EV $j \in V$, subject to the EV charging dynamics $x_j(t) = x_j(t-1) + \delta u_j(t)$, where δ = charging efficiency, $x_j(t)$ = EV state-of-charge at time t

Given task description and code example, LLMs can:

- Ask user for parameters of `Solve_EV(...)`
- Generate code to invoke `Solve_EV(...)`
- Accurately interpret the output of the code and explain the results to the user

LLM4EV: Example

LLM4EV

System: You are an AI assistant specialized in solving EV charging problems. You have been provided with a

predefined function called `solve_EV()` that is capable of addressing various EV charging problems:

```
def Solve_EV(num_of_vehicles, timesteps,  
             initial_states, max_power,
```

```
             terminal_states, dept_time,  
             power_capacity, plot_fig):
```

```
...
```

User: Can you help me to schedule the charging of electric vehicles?

Assistant: Of course, I'd be happy to help. To provide the best result, I need some specific details from you. Could you

please tell me the following:...

What are the initial states (charge levels) of your vehicles?

Please list for each vehicle if more than one...

User: 3. They all start from zero, ...

Assistant: Thank you for the information. Based on your input, we can utilize our EV charging solver as follows:

```
# starting from zero for all vehicles  
initial_states = [0, 0, 0, 0, 0]
```

```
...
```

3. LLM4SA: Methodology

- In-context learning + prompt engineering to attain the zero/few-shot situation awareness
- Circumvents cumbersome post-hoc fine-tuning

LLM4SA: Application

Goal: To achieve situation awareness based on scenario images using multimodal capabilities of **GPT-4V**

The paper designs 4 approaches:

1. One image query and directly asking if wildfire exists in the image
2. One image query and applying prompt engineering
3. Multiple image examples along with ground true labels as the engineered prompts
4. Based on (3), adding language explanations associated with true labels

LLM4SA: Example

LLM4SA

Image inputs:



Detection target



Few-shot prompts

System: This dataset contains satellite images about wildfire in Canada, using Longitude and Latitude coordinates for each wildfire spot (> 0.01 acres burned) found. Areas after wildfire may demonstrate different color in satellite images. You are a professor of forestry, and good at observing satellite images. I will give you several examples of satellite images with “yes” or “no” to specify if wildfire happened. The truths of the first 5 images are “yes”, “yes”, “yes”, “no”, “no”.

Question: Now, let's think step by step, and tell me, had wildfire happened in the last picture?

Answer: ...Considering this observation, it is likely that the last picture depicts an area where wildfires have occurred.

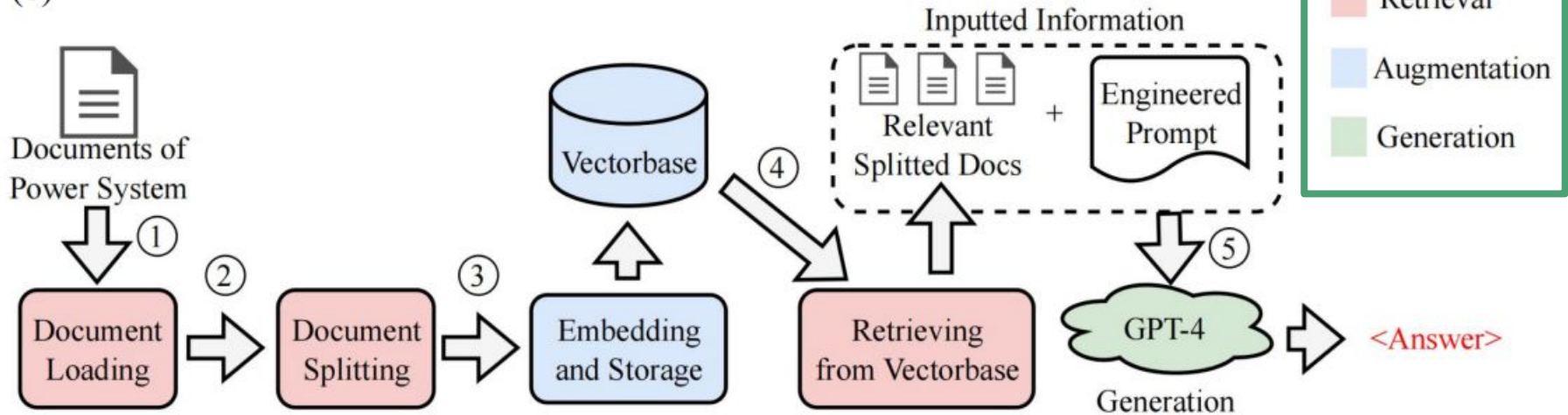
LLM4SA: Performance Evaluation

Approach (4) achieves the highest accuracy of 91% due to explanations of labels.

Approach (3) achieves accuracy of 86% due to effectiveness of few-shot prompting.

4. LLM4Doc: Methodology

(c)



- ① Load documents. ② Split documents into small pieces of text. ③ Transform textual data into vectors for storage. ④ Retrieve relevant information from vectorbase. ⑤ GPT-4 conduct QA based on retrieved information and prompts.

LLM4Doc: Application

Goal: For **profiling and retrieving knowledge** from power system documents

The paper classifies questions into 2 types:

- General questions
 - *E.g. “Please summarize this file.”*
- Technical questions
 - *E.g. “What is the phaselock loop Synchronization in this file?”*

LLM4Doc: Example

LLM4Doc

Directly ask questions.

Question: What is Synchronization?

Answer: The synchronization requires generators to maintain synchronism where possible and continue to inject current to support system stability.

Directly ask questions.

Question: What is phase-lock loop Synchronization?

Answer: I don't know.

Ask based on RAG.

Question: What is Synchronization?

Answer: ... **synchronization** in this document refers to the synchronization status between the inverter and the grid during Bulk-Power System (BPS) events. **Specifically**, when a BPS event (such as a fault) causes instantaneous synchronization loss, ... **The purpose of synchronization** is to ensure that the inverter can continue to provide power and resynchronize with the grid...

Ask based on RAG.

Question: What is phase-lock loop Synchronization?

Answer: ... **Specifically, PLL synchronization refers to** the inverter continuing to inject grid current during system disturbances, locking the phase-locked loop to the last synchronization point, and continuing to inject current into the grid at its calculated phase until the phase-locked loop can resynchronize. ... **maintaining PLL synchronization is important for** protecting and controlling ...

Limitations of the paper

- **OPF** - Expensive computation, sample-specific optimization
- **EV** - Code template dependent
- **Knowledge Retrieval** - Answer inconsistency, lack of specific knowledge
- **Situation Awareness** - Unstructured and multi-source input data, e.g., meter readings, image snapshots

Conclusion

- LLMs show promising applications in power systems
- LLMs show notable performance without the need for fine-tuning
- LLMs offer efficient tools for system operators, policymakers, and end users

Our thoughts

- Can expand on the set of tasks for EV as a generalization
- Too less test data in SA
- Fine-tuning in SA can provide better results
- Newer models for embedding and retrieval in document retrieval



Thank you!
Questions?
