SoutheastCon 2026 – Technical Program

Large Language Models for Nodal Analysis in Circuits Education: An Evaluation

GrowForward

Huntsville, AL

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IEEE

The Harsh Reality of Teaching Nodal Analysis at Circuits I

100+
Students per foundational Circuits I class.

2-3
Graduate teaching assistants for support.

1-2
Weeks allocated to teach nodal analysis.

The observation: Students lack the individualized, step-by-step guidance to master the critical foundation of Nodal Analysis.

Where Students Get Stuck in Nodal Analysis

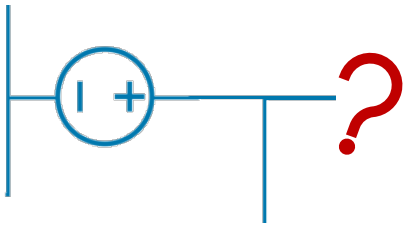
Inconsistent use of sign conventions

$$\frac{V_1 - V_2}{R_1}$$

Error in formulating branch current expressions

$$I_1 + I_2 = I_3$$

Failure to construct complete KCL equation



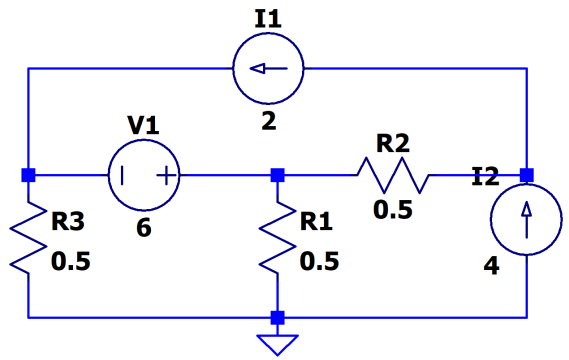
Difficulty identifying and formulating supernodes

$$[A][x] = [b]$$

Math error when solving the resulting systems of equations

A Proposed Teaching Workflow

Students build Schematic in LTSpice



SPICE Netlist generated from LTSpice

```
V1 N003 N001 6
I1 N002 N001 2
I2 0 N002 4
R1 N003 0 0.5
R2 N002 N003 0.5
R3 N001 0 0.5
```

Large Language Model Guidance

Structured multi-step reasoning prompt.

Already implemented in class

To be studied in this work

Paper Overview & Contribution

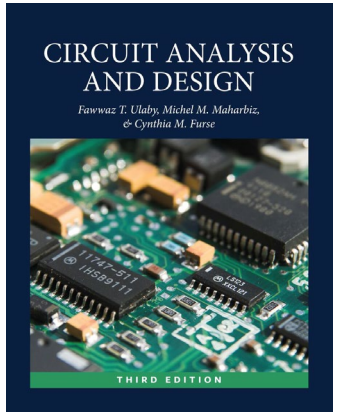
Introduction of a novel LLM-integrated pedagogical workflow to support Nodal Analysis in circuits education.

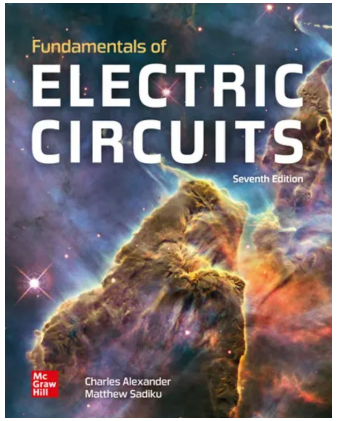
Evaluations of the state-of-the-art LLMs in solving undergraduate-level Nodal Analysis tasks (w/o dependent sources).

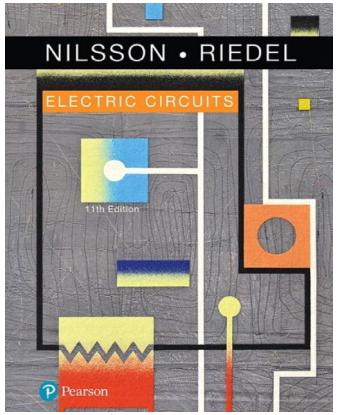
Nodal Analysis Problem Bank

50

Circuits from 3 textbooks & our exam







Circuits containing ≥ 2 independent sources

Feature mixed voltage and current sources

Strictly require supernode formulation

Note: Nodal analysis involving dependent sources are excluded from the evaluation, due to the difficulty students may face in setting up schematics in LTspice

Evaluation on LLMs

OpenAI

- GPT-5 (Flagship)
- GPT-5 mini (Lightweight)

Google

- Gemini 2.5 Pro (Flagship)
- Gemini 2.5 Flash (Lightweight)

Anthropic

- Claude Sonnet 4.5 (Flagship)
- Claude Haiku 4.5 (Lightweight)

The Structured Prompt Architecture

1. Task Description

Analyze using nodal analysis based on the netlist.

→

2. Solution Procedure

Explicit 3-step nodal analysis procedure.

→

3. Worked Example

Fully solved examples using LaTeX mathematical notation.

→

4. Unsolved Task

The target SPICE netlist.

Single-Shot Prompt Example

Task Description

Analyze the circuit defined by the Netlist below using Nodal Analysis.

Solution Procedure

Step 1: Identify all extraordinary nodes (nodes connected to three or more elements). Assign node voltages to all extraordinary nodes except Ground (Node 0).

Step 2: Apply Kirchhoff's Current Law (KCL) at each assigned node voltage.

Step 3: Solve the resulting simultaneous equations to determine the unknown extraordinary node voltages. Apply the concept of a supernode if a voltage source is present between two non-reference nodes. Report unknown extraordinary node voltages only in the final result.

Worked Example

Netlist

```
V1 N001 0 10
V2 N003 N002 5
R1 N003 0 8
R2 N002 0 6
R3 N003 N001 2
R4 N002 N001 4
```

Solution

Step 1:

Identify extraordinary nodes N001, N002, and N003. Assign voltages V_{N001}, V_{N002}, and V_{N003}.

Note that voltage source V2 connects N003 and N002, creating a supernode where $V_{N003} - V_{N002} = 5$.

Step 2:

Node N001 is fixed by voltage source V1: $V_{N001} = 10$.

For the supernode (N002, N003), assume all currents leave the nodes:

$$\frac{V_{N003}}{8} + \frac{V_{N003} - 10}{2} + \frac{V_{N002}}{6} + \frac{V_{N002} - 10}{4} = 0$$

Simplifying yields: $3V_{N003} + 2V_{N002} = 36$.

Step 3:

Solve the system:

$V_{N001} = 10$,

$V_{N003} - V_{N002} = 5$,

$3V_{N003} + 2V_{N002} = 36$.

Result: $V_{N001} = 10$ V, $V_{N002} = 4.2$ V, $V_{N003} = 9.2$ V.

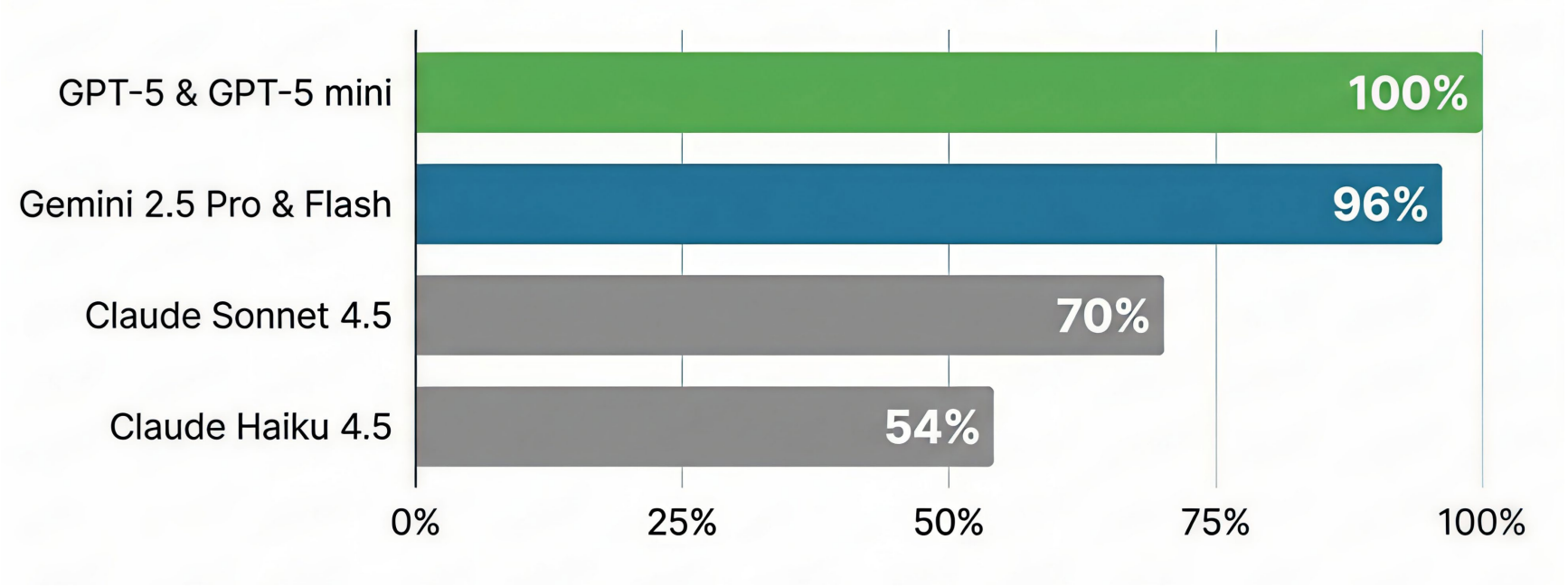
Unsolved Task

Apply the same procedure to the following Netlist:

...

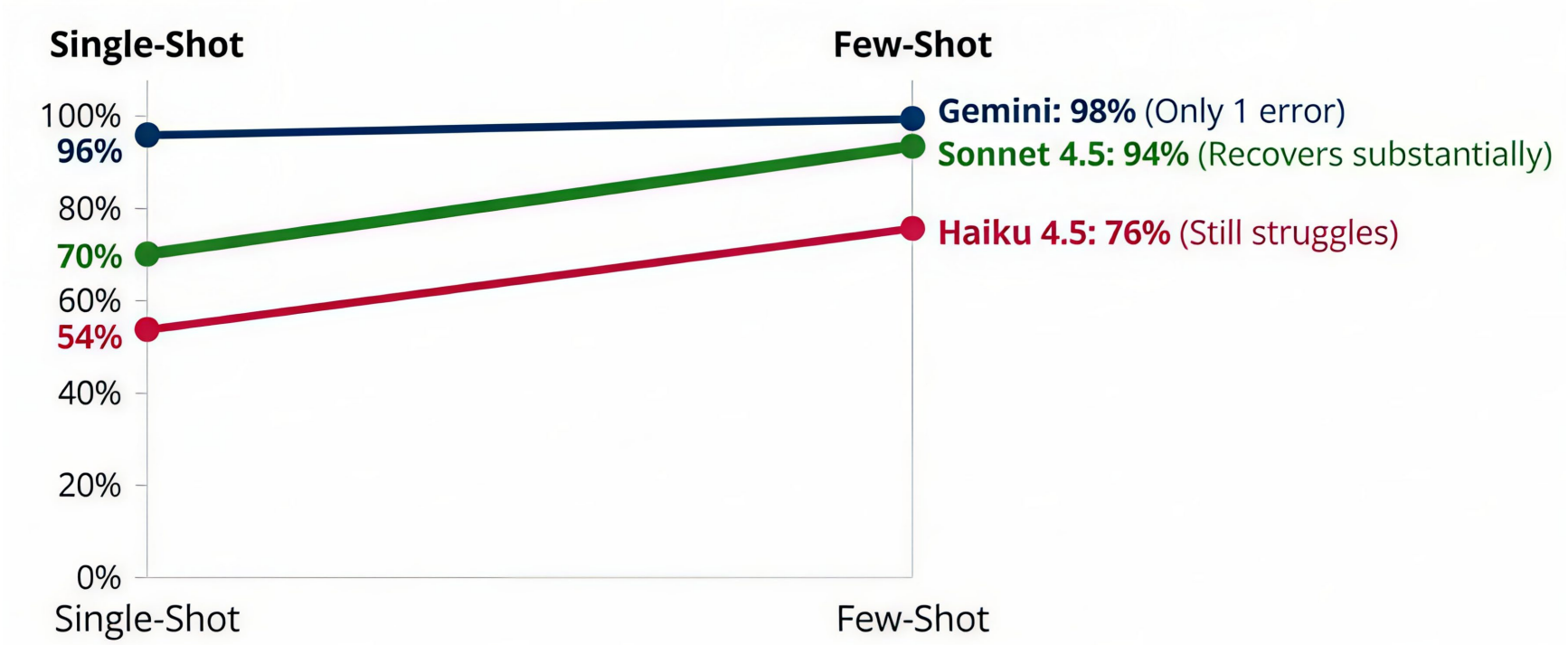
Single-Shot Prompt Results

Single-Shot Prompt: Only 1 worked example, about 550 tokens



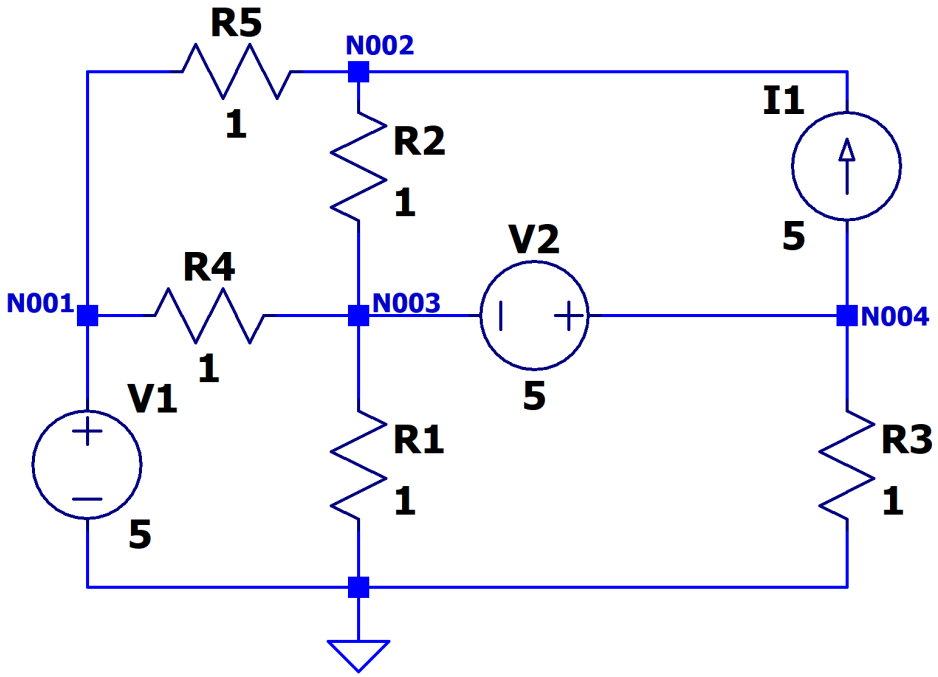
Few-Shot Prompt Results

Few-Shot Prompt: Use 5 worked example, about 2,250 tokens



Error Case Analysis 1

Claude Sonnet 4.5, few shot prompt.
Wrong current source direction in analysis



Claude Response:

For Node N002:

$$\frac{V_{N002} - V_{N003}}{1} + \frac{V_{N002} - 5}{1} + 5 = 0$$

For the supernode of N003 & N004:

$$\frac{V_{N003}}{1} + \frac{V_{N003} - 5}{1} + \frac{V_{N003} - V_{N002}}{1} + \frac{V_{N004}}{1} - 5 = 0$$

Correct Analysis:

For Node N002:

$$\frac{V_{N002} - V_{N003}}{1} + \frac{V_{N002} - 5}{1} - 5 = 0$$

For the supernode of N003 & N004:

$$\frac{V_{N003}}{1} + \frac{V_{N003} - 5}{1} + \frac{V_{N003} - V_{N002}}{1} + \frac{V_{N004}}{1} + 5 = 0$$

Error Case Analysis 2

Claude Haiku 4.5, few shot prompt.
Made 12 incorrect solutions out of the 50 evaluated circuits
(single circuit analysis may include multiple error types)

- **4 occurrences** Current-source sign error in all-node KCL equation.
- **3 occurrences** Current-source sign error in supernode KCL equation.
- **2 occurrences** Failure to analyze voltage-source–resistor branch.
- **1 occurrence**: Failure to analyze current-source–resistor branch.
- **1 occurrence**: Arithmetic error involving kΩ.
- **1 occurrence**: Applying KCL to a fixed voltage node.
- **1 occurrence**: Incorrect supernode construction.
- **1 occurrence**: Omitted current-source term in KCL equation.

Get Ready for the Classroom

Final Verdict

GPT and Gemini models are highly capable of supporting undergraduate nodal analysis right now, effectively serving as scalable, personalized TAs.

Pedagogical Strategy

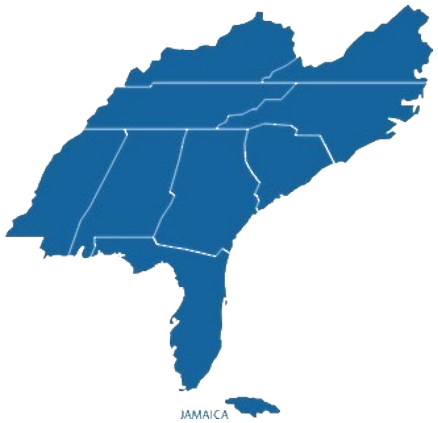
Institutions should train students on LTspice generation first, then provide engineered prompt templates to guarantee LLM accuracy.

Future Work

- Expanding to dependent sources and Mesh/Thévenin analysis.
- Transitioning from text-based netlists to direct circuit image inputs using large multimodal models.

Any Questions ?

IEEE Region 3



Large Language Models for Nodal Analysis in Circuits Education: An Evaluation

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Thank You!

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Thanks for joining us in Huntsville!