De-energized Lines Can Still Start Fires. Understanding the Risks and the Effects of Grounding

Robert James (PG&E System Protection), Scott Hayes (PG&E System Protection)

Outline

I. Introduction
II. Basic Physics
    A. Electric Field and Mutual Capacitance
    B. Magnetic Field and Mutual Inductance
    C. Shortcomings of KVL
III. Transmission Line Grounding
    A. Ungrounded Line
    B. Single Ground
    C. Grounded at Both Ends
    D. Multiple Grounds
    E. Double Circuit Example using EMTP
IV. Conclusion

Fire Risk of De-energized Lines…..Really?!?

- "Faults" on de-energized lines cannot be detected
- De-energized lines are a shock hazard

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- De-energized lines are a shock hazard
- Fires have been started at TPG locations
- Many utilities are vulnerable

Thomas Fire

Maui Fire

Smokehouse Creek Fire

Camp Fire

Fire Risk of De-energized Lines…..Really?!?

- "Faults" on de-energized lines cannot be detected
- De-energized lines are a shock hazard
- Fires have been started at TPG locations
- Many utilities are vulnerable
- Decommissioning Lines
- Long Term Clearances
- Public Safety Power Shutoff (PSPS)

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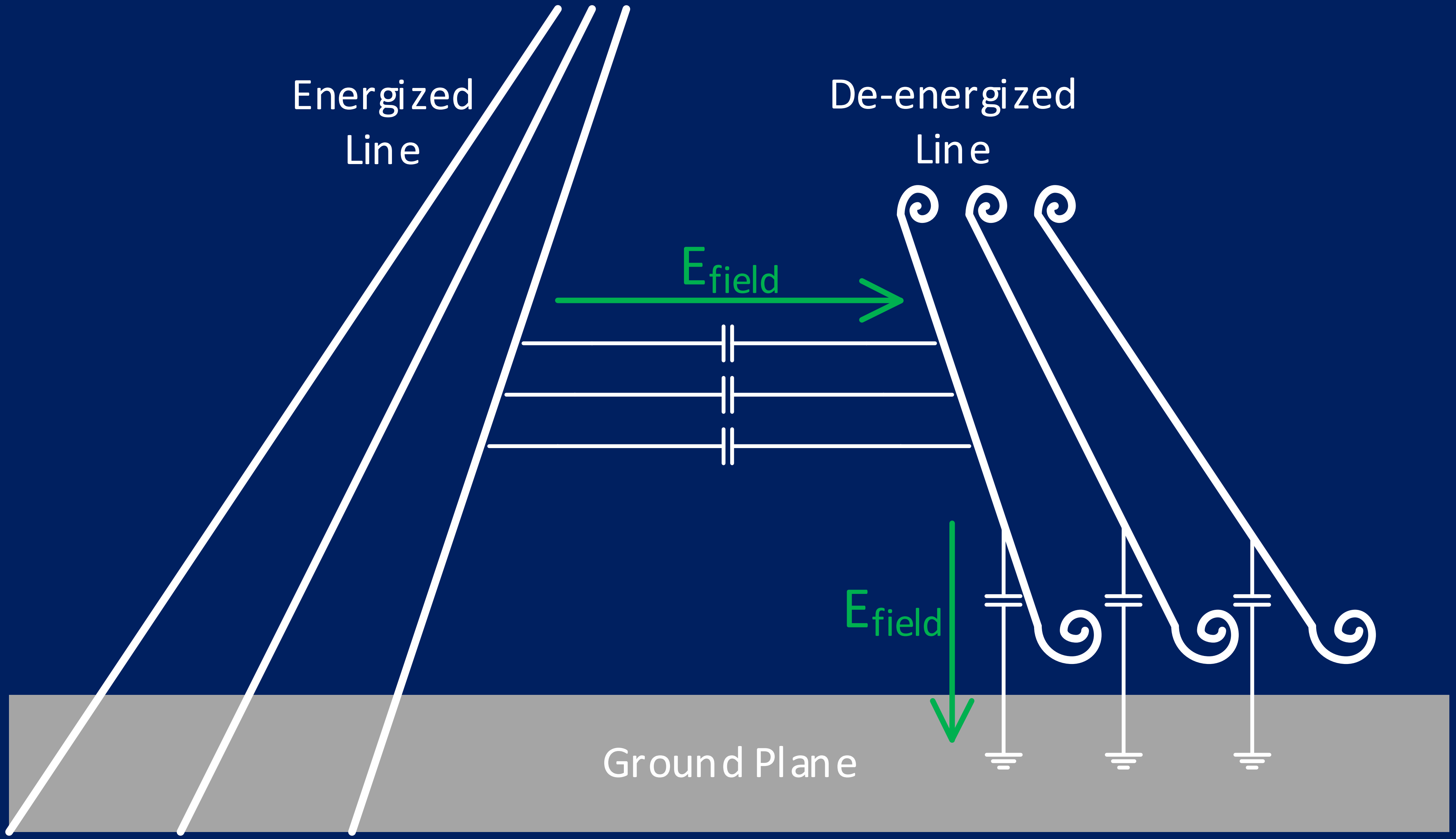
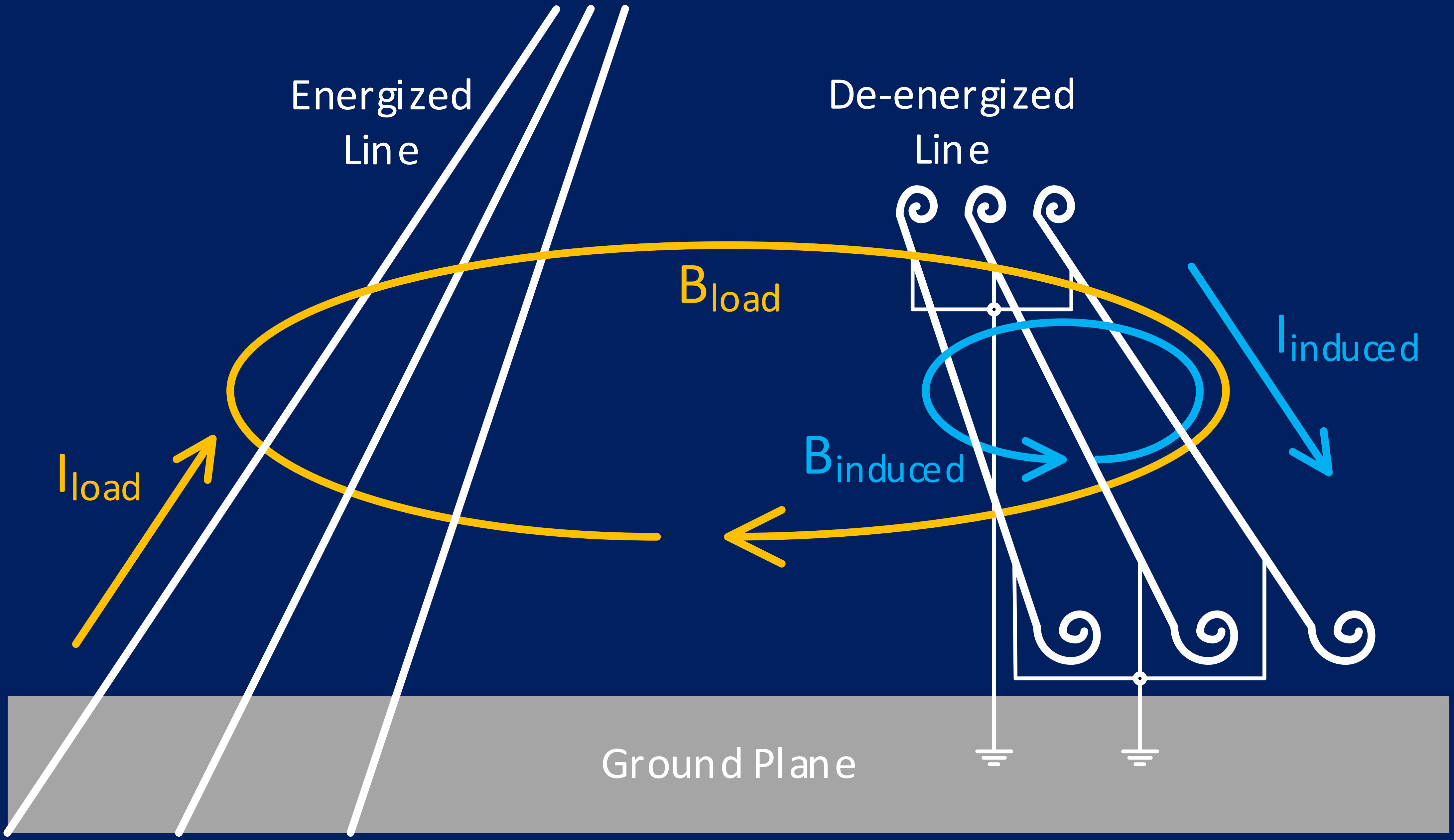
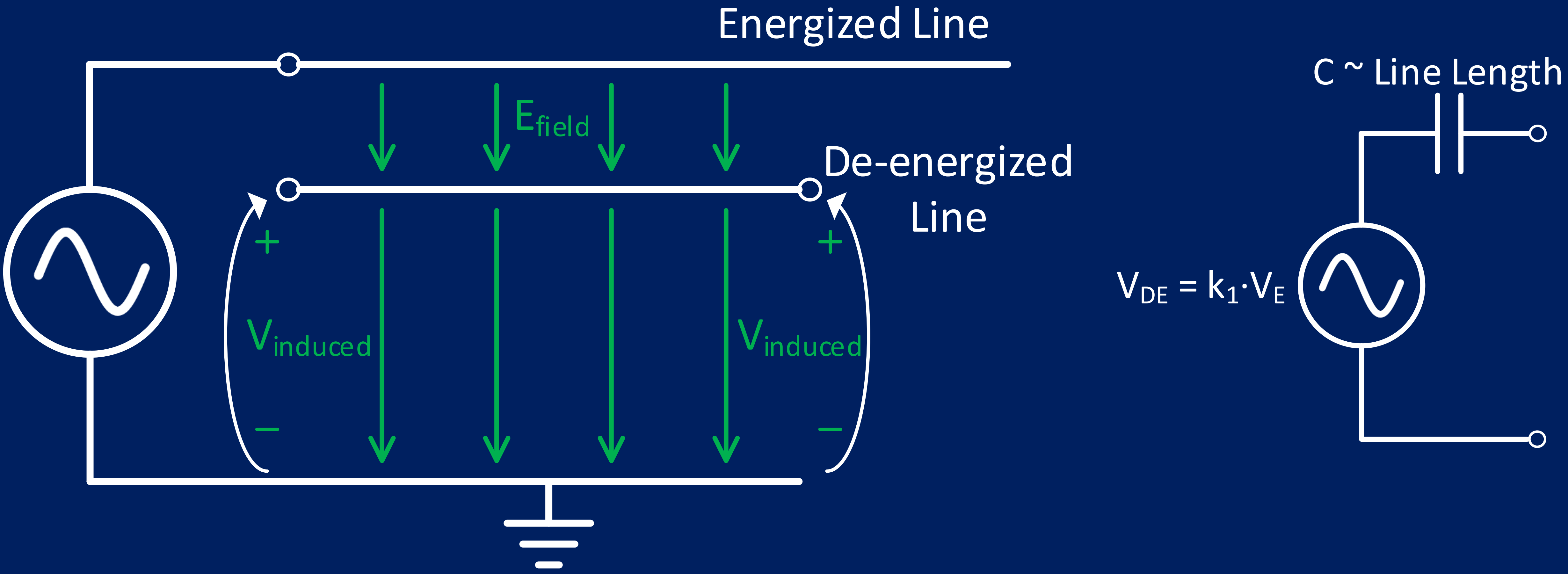
Basic Physics: E-field



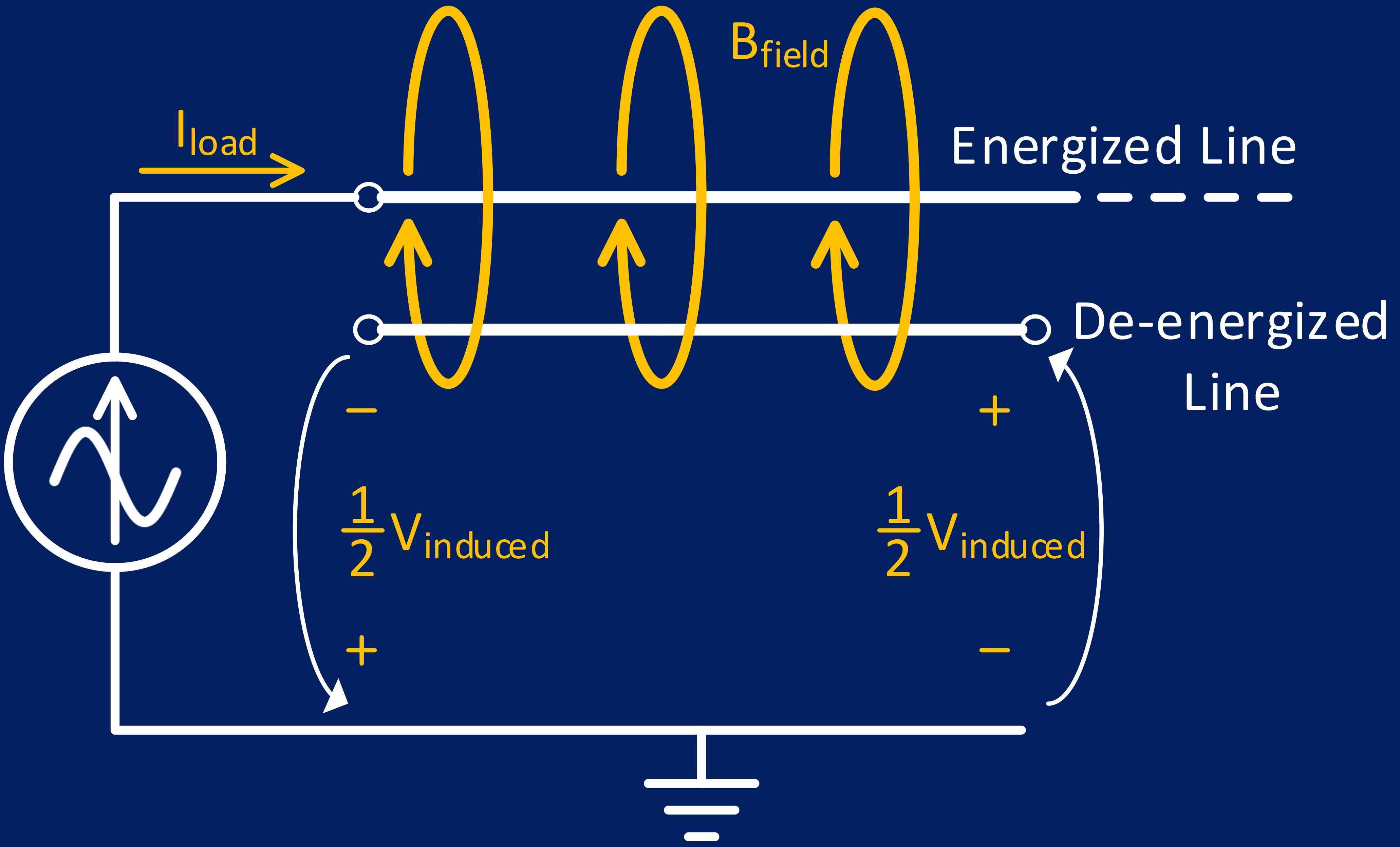
Basic Physics: B-field



Single-phase Circuit: Electric Field Induction



Single-phase Circuit: Magnetic Field Induction



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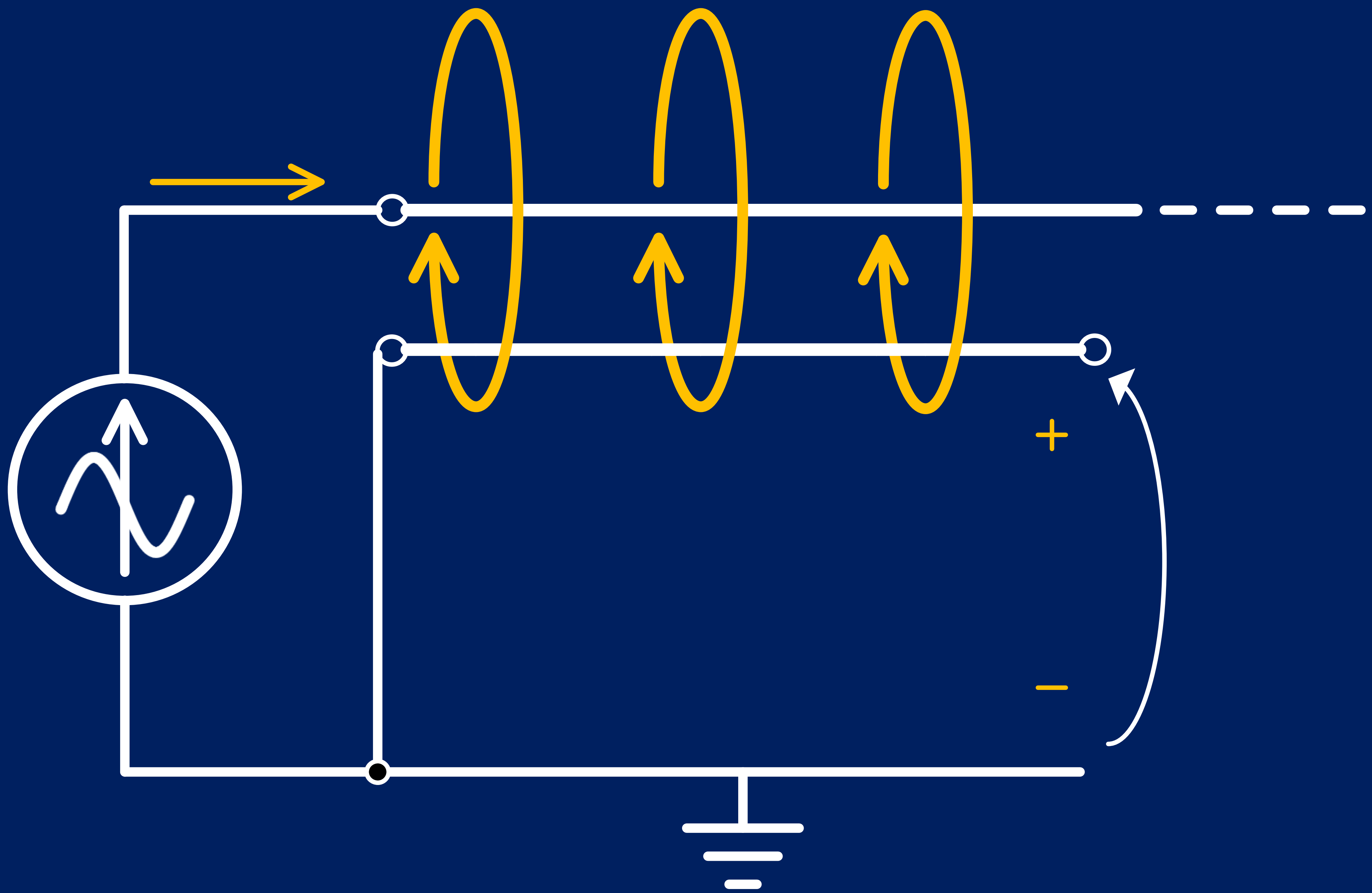

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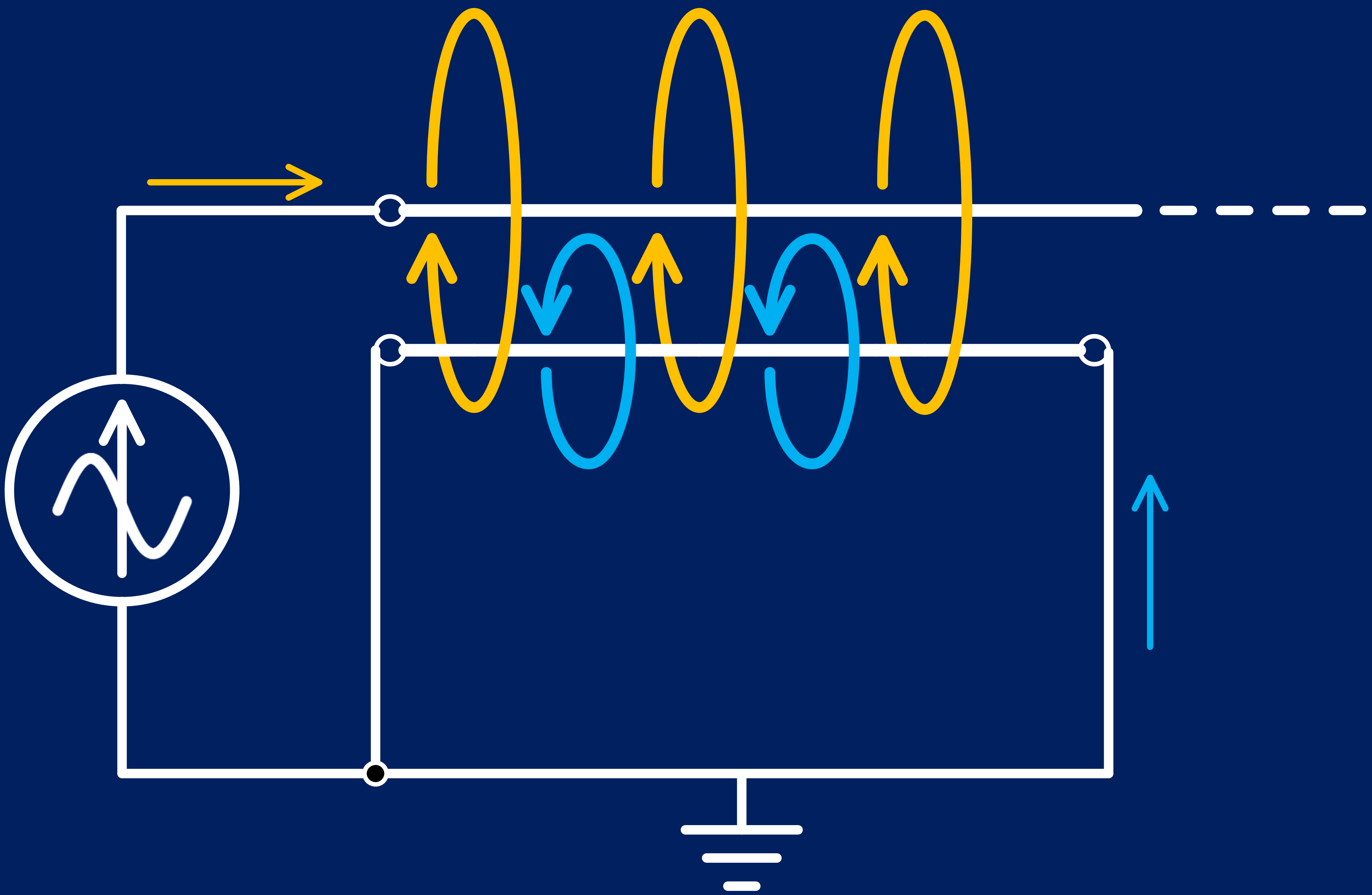

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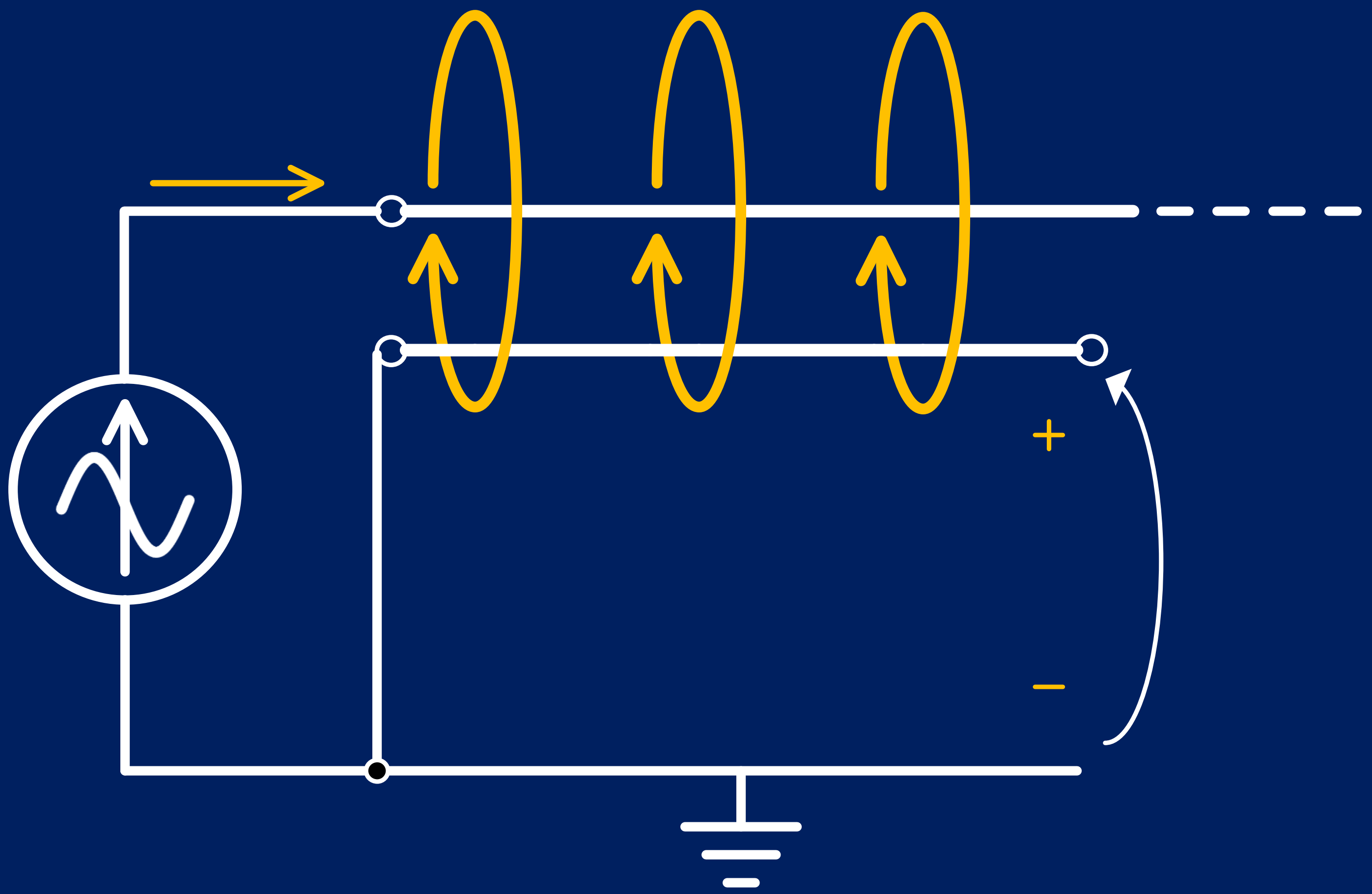
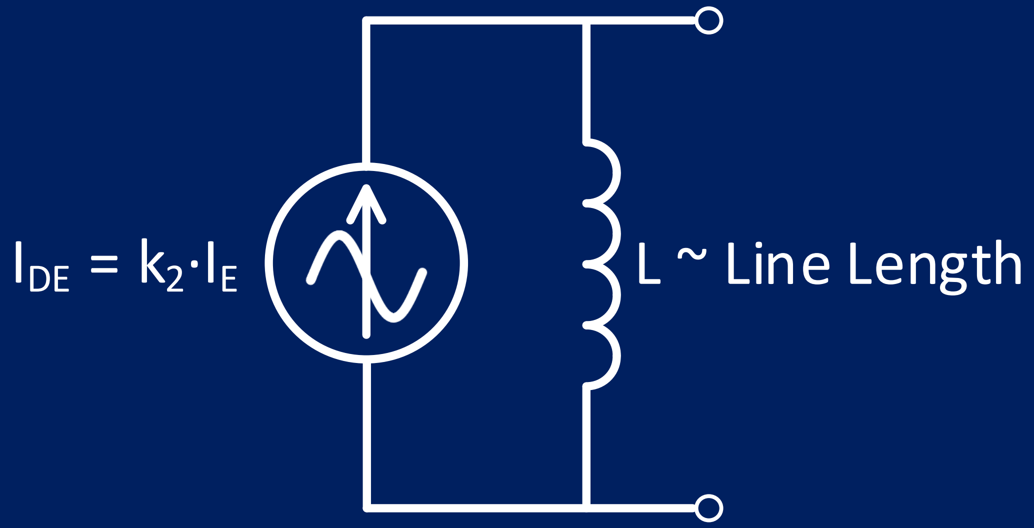




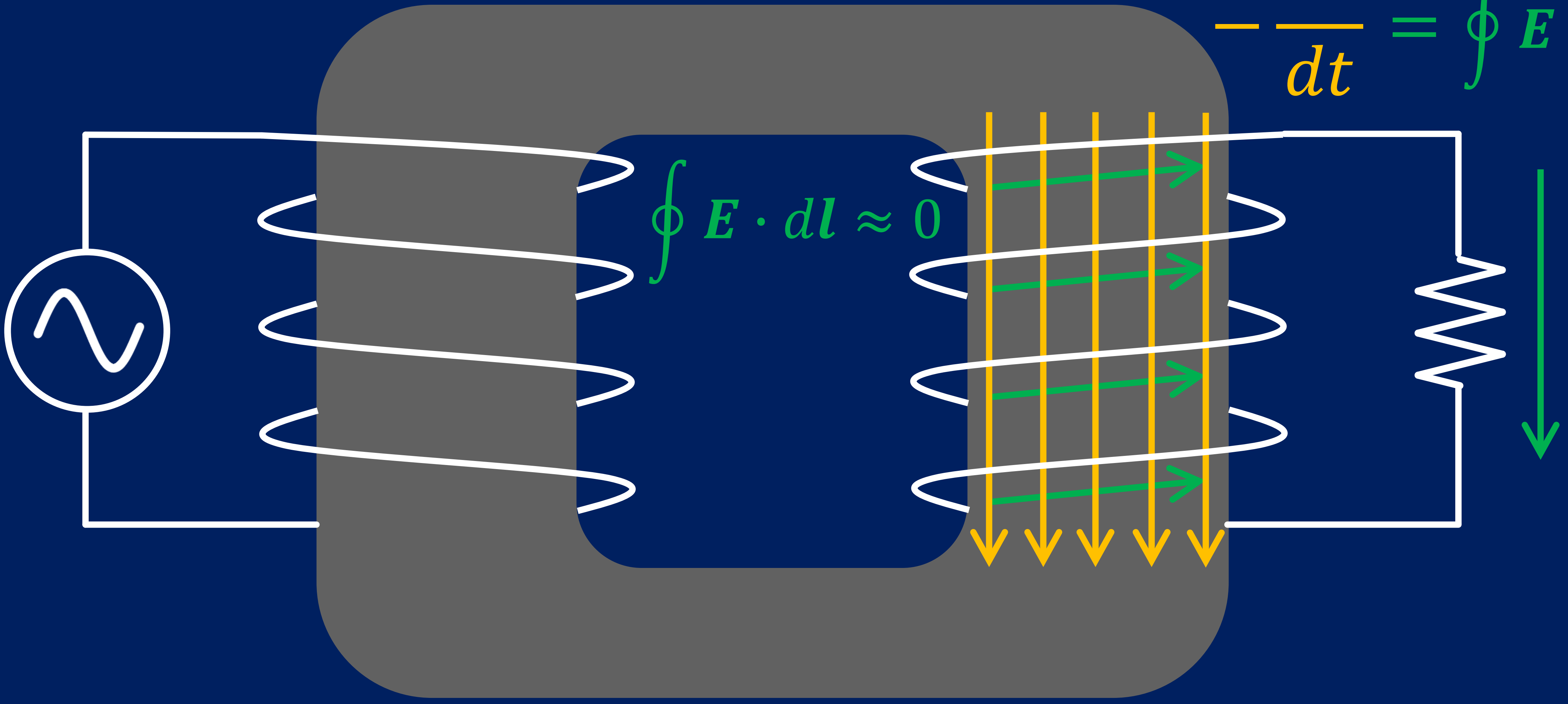
Shortcomings of KVL

KVL: $$V_{closed\ loop} = \sum_i V_i = 0$$

Faraday's Law: $$V_{closed\ loop} = \oint \boldsymbol{E} \cdot d\boldsymbol{l} = -\int \frac{\partial \boldsymbol{B}}{\partial t} \cdot d\boldsymbol{A}$$

Shortcomings of KVL

$$-\frac{d\phi}{dt} = \oint \boldsymbol{E} \cdot d\boldsymbol{l}$$



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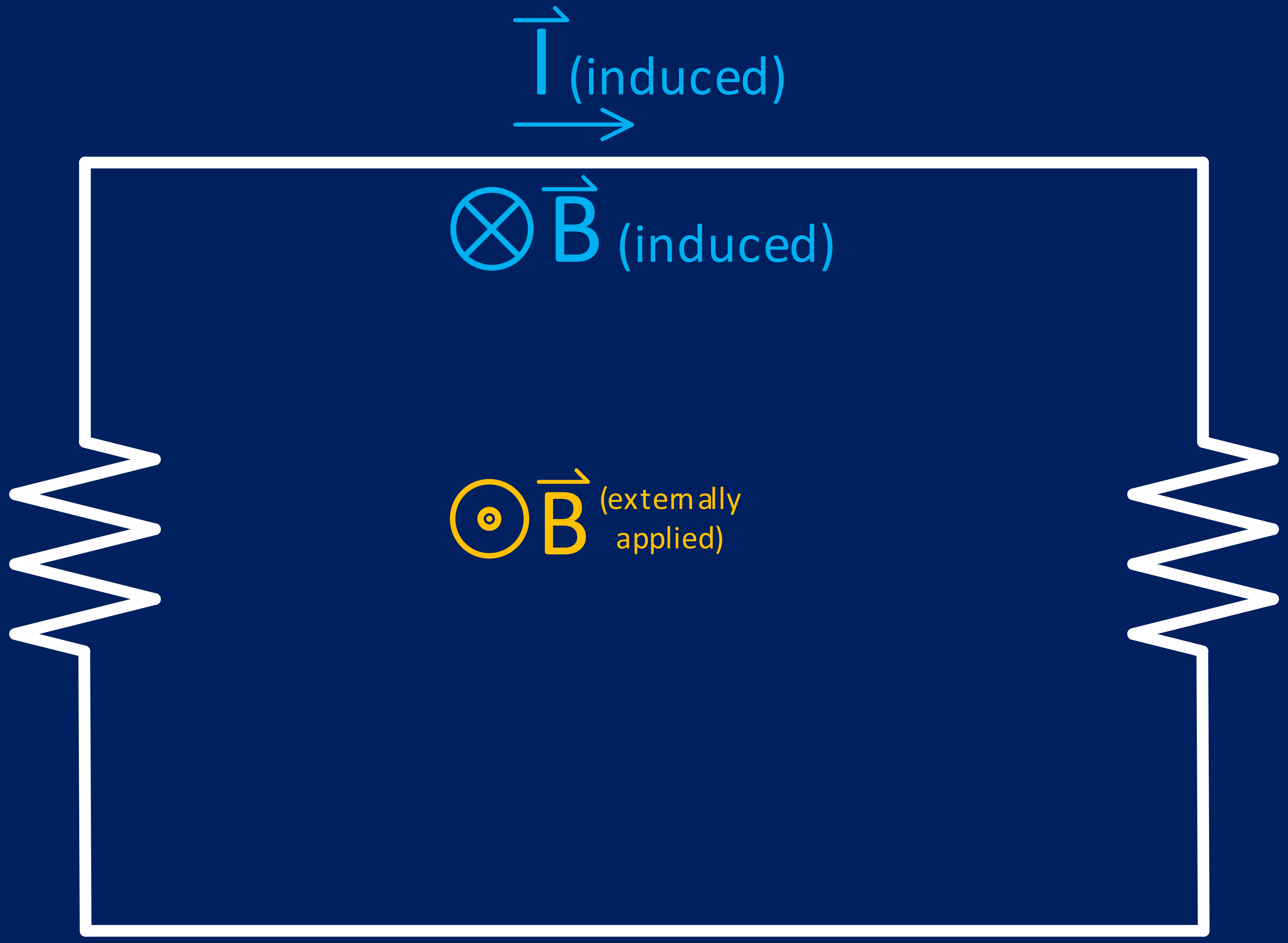

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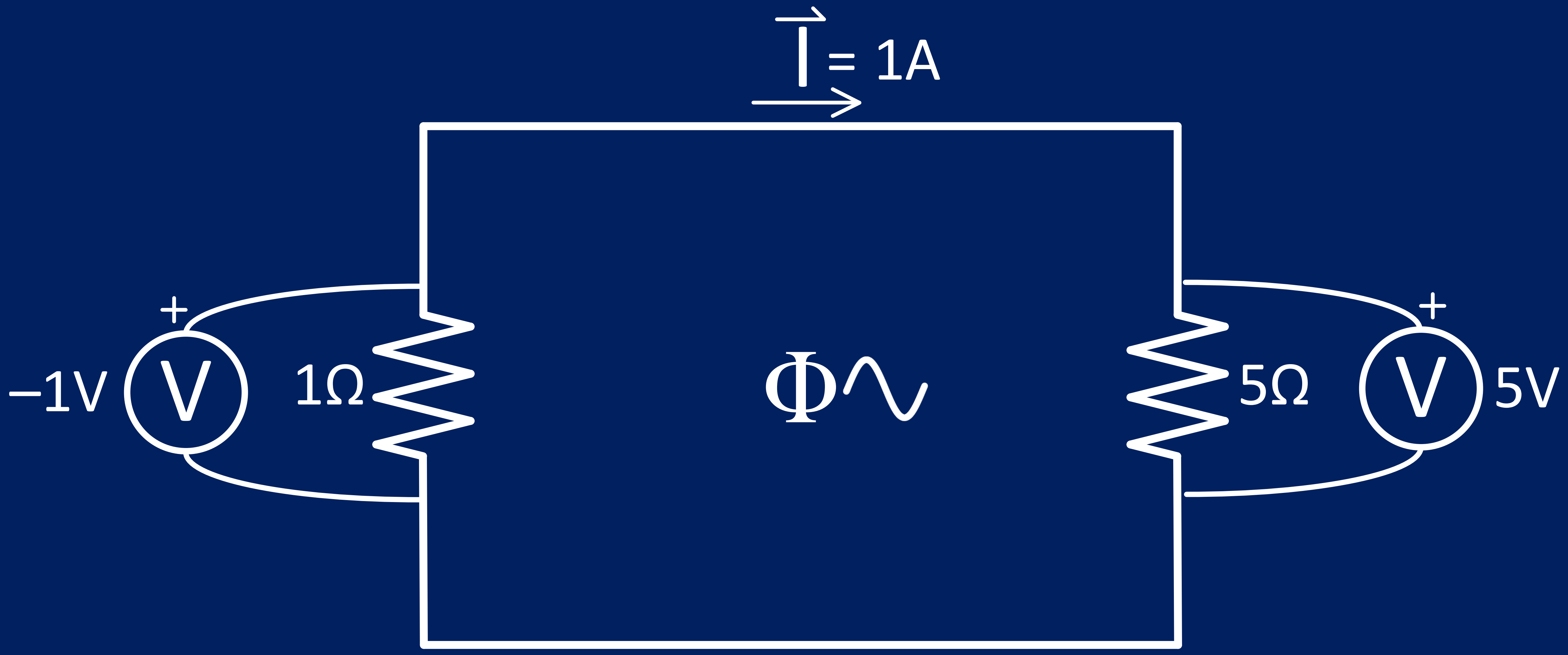

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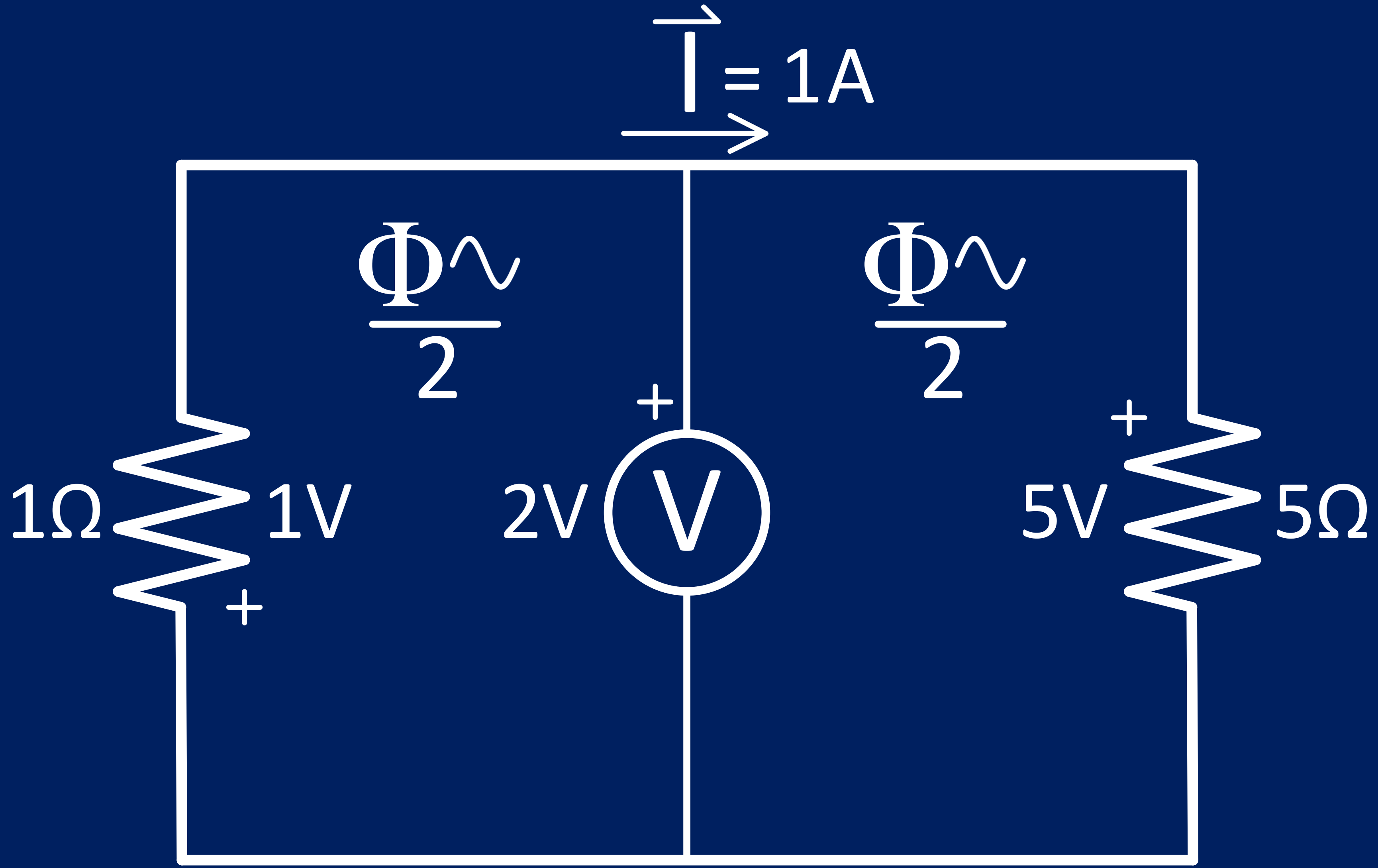
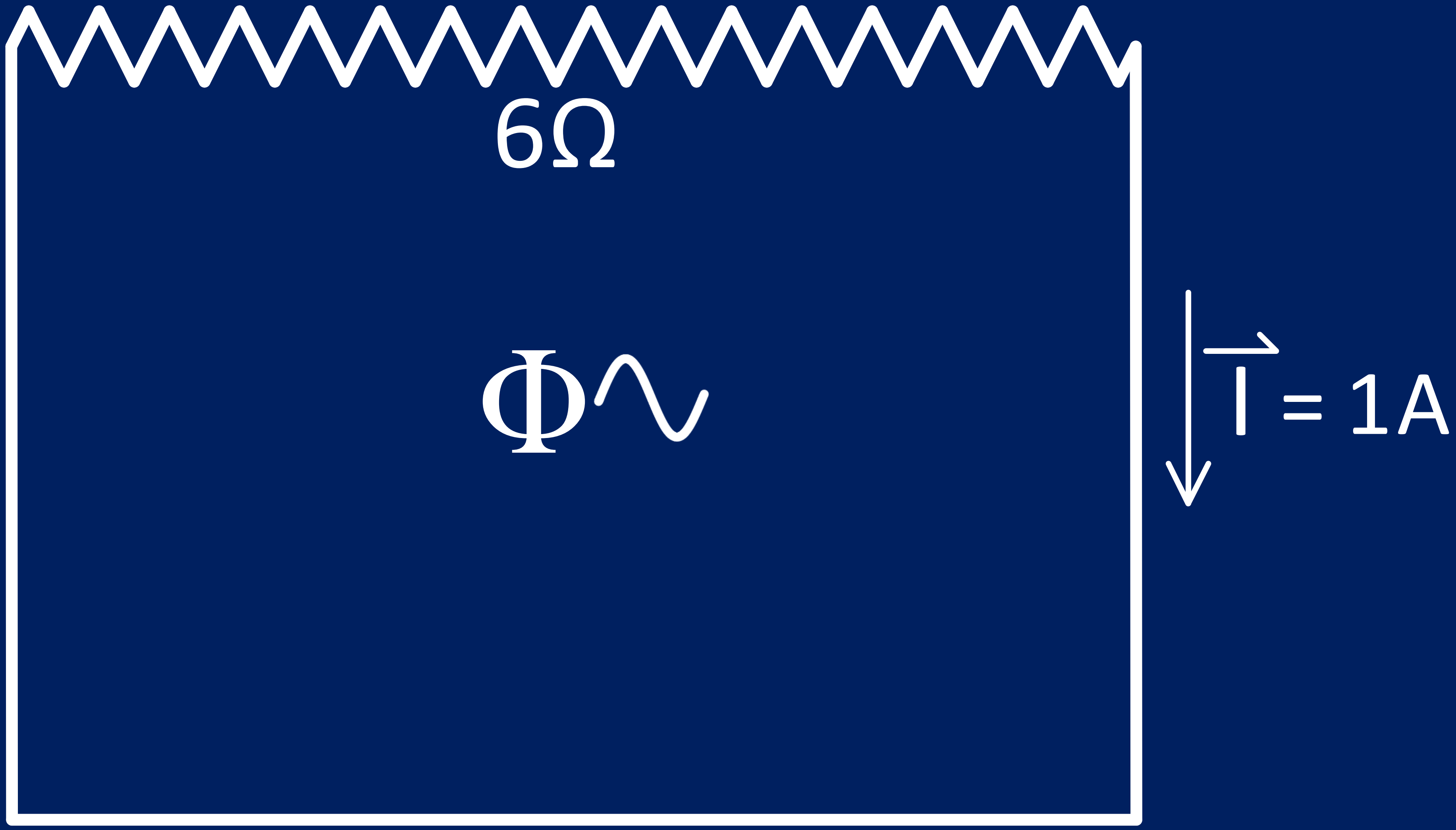


Uniformly Distributed Resistance



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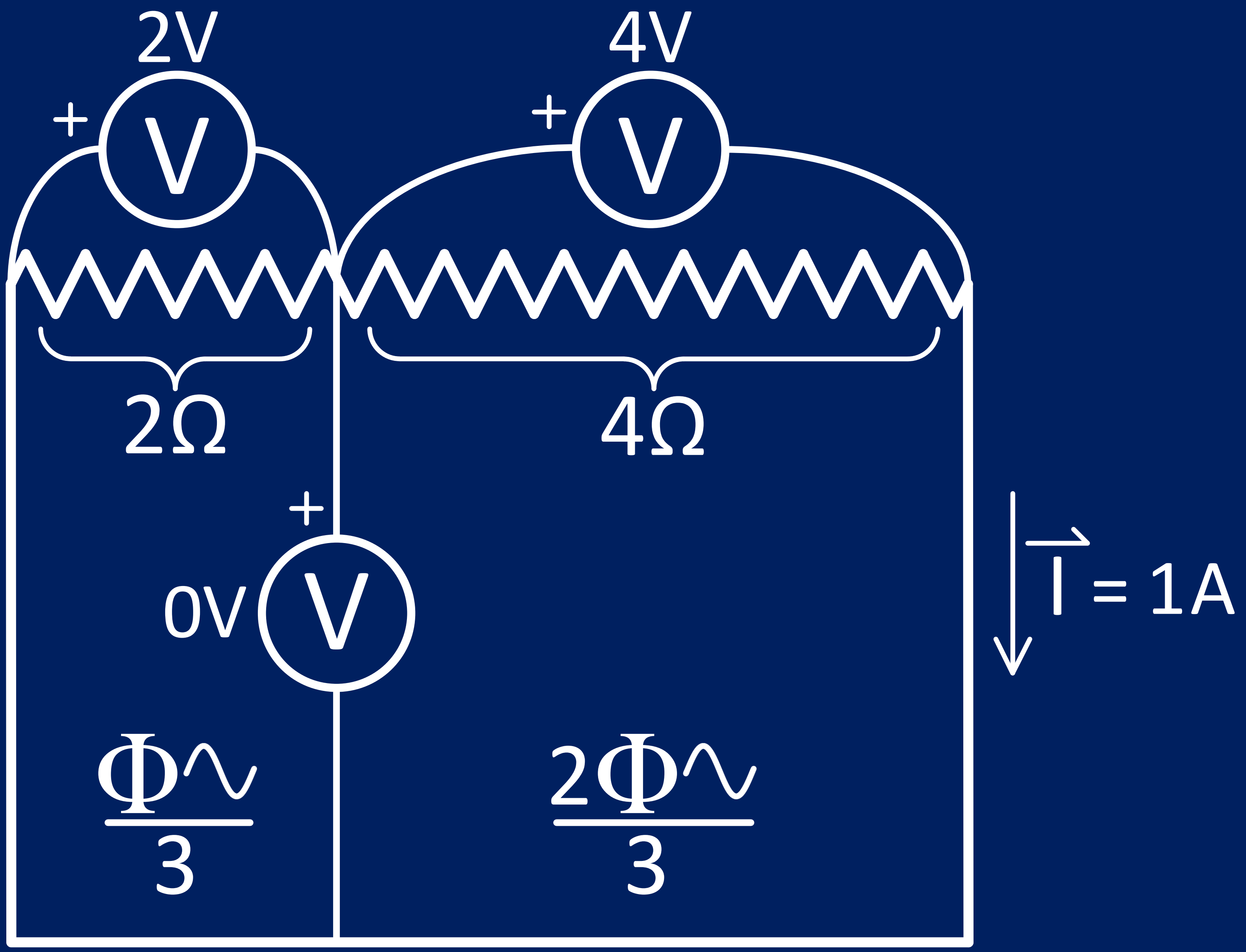

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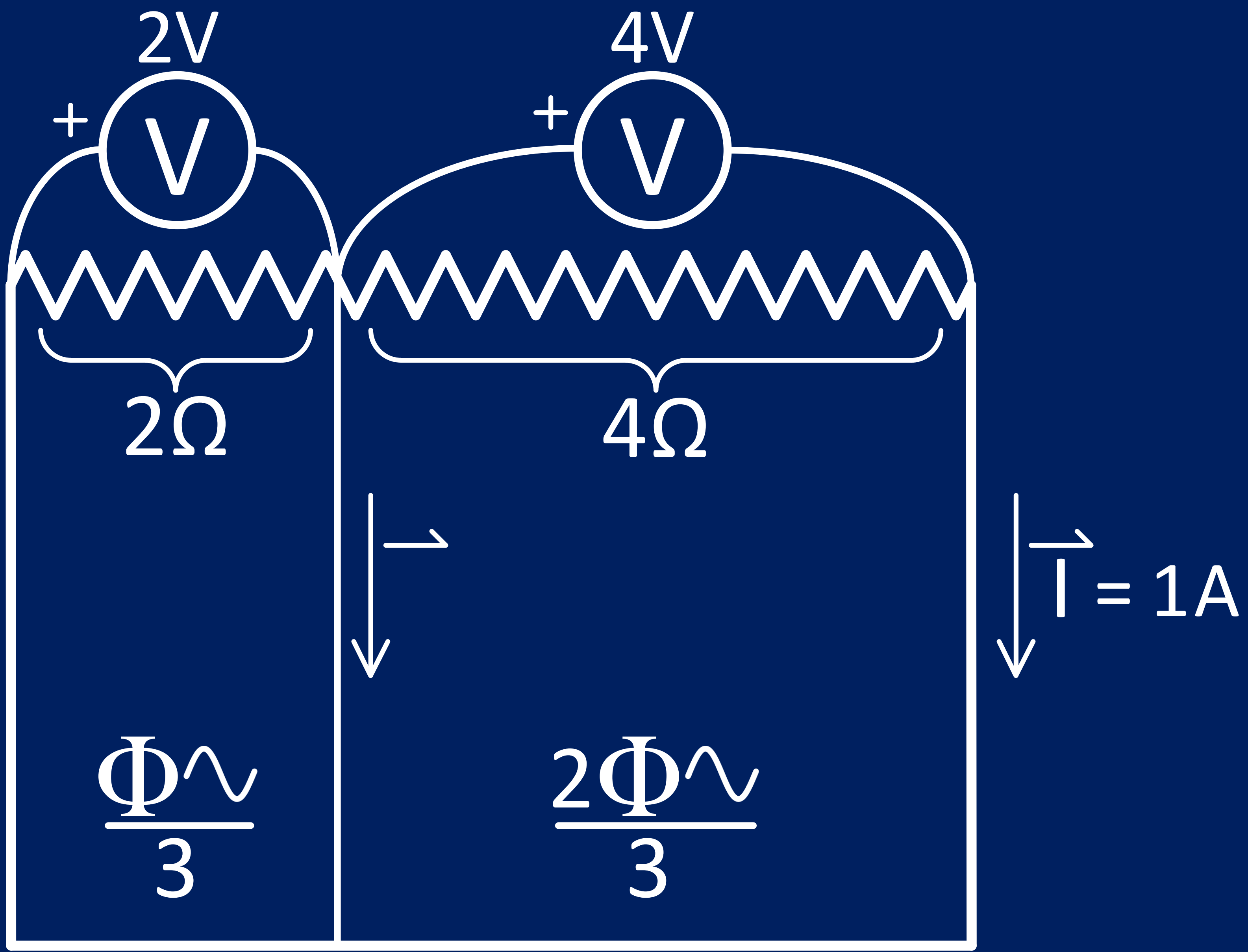
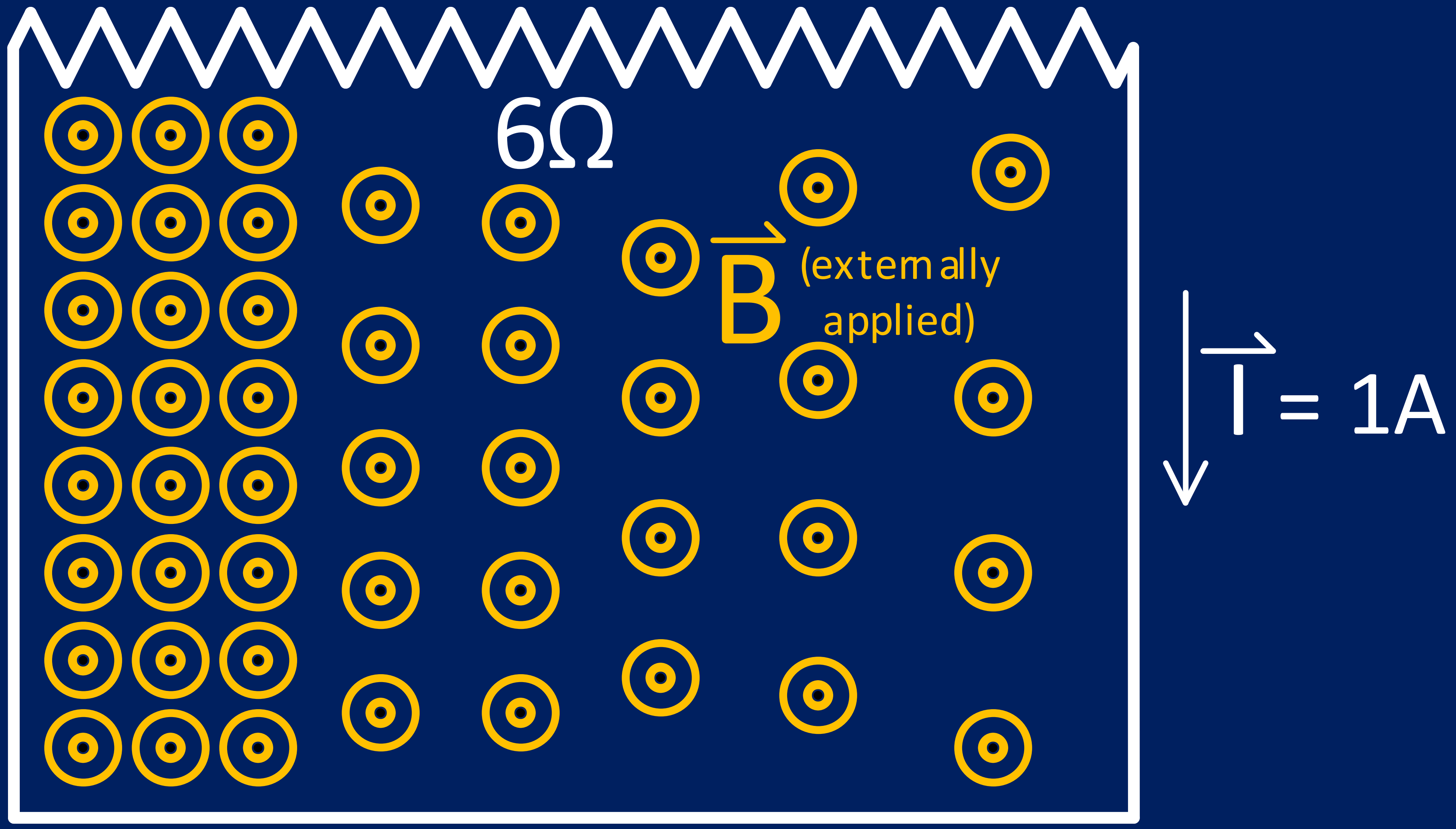


Non-Uniform Magnetic Field



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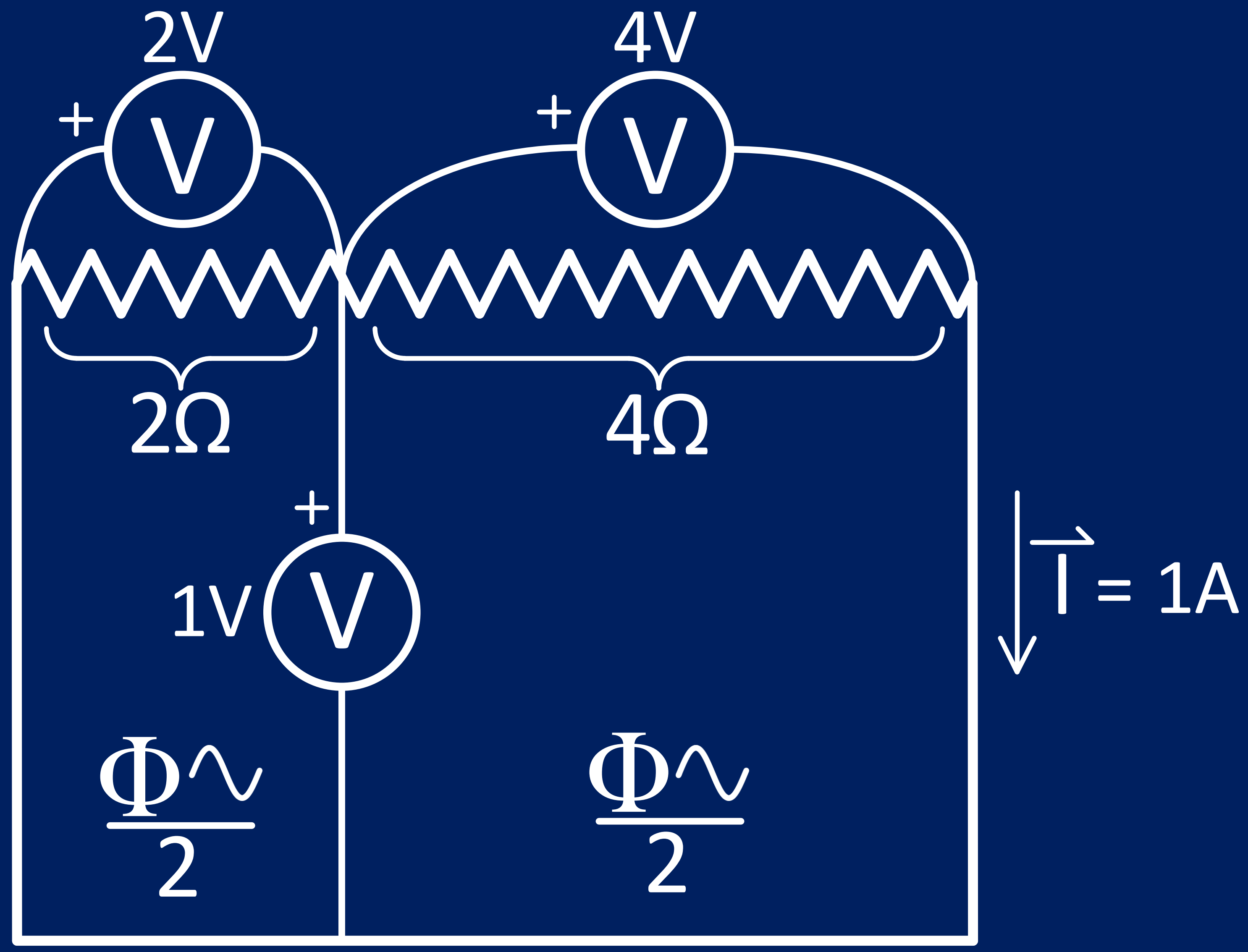

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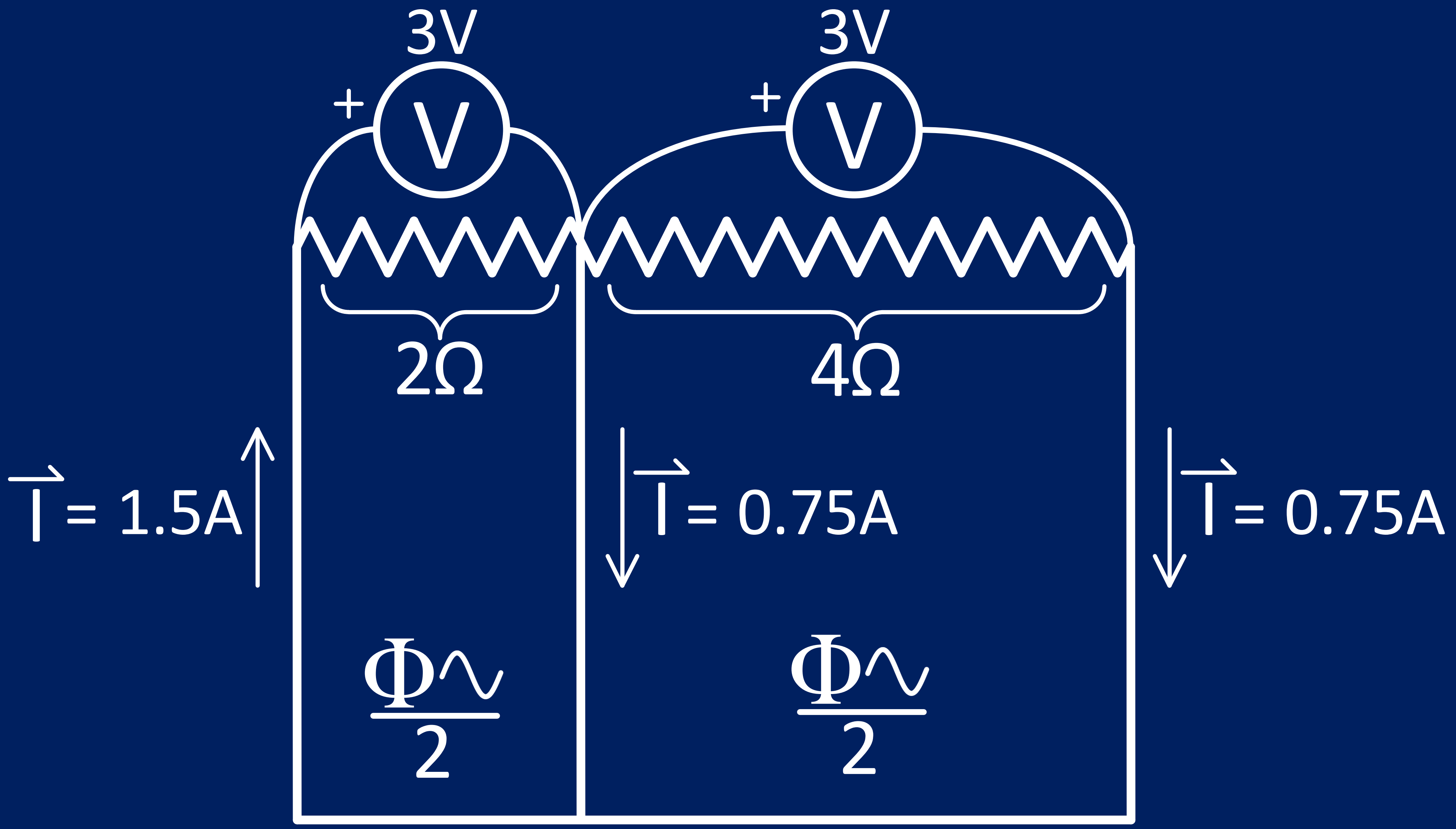

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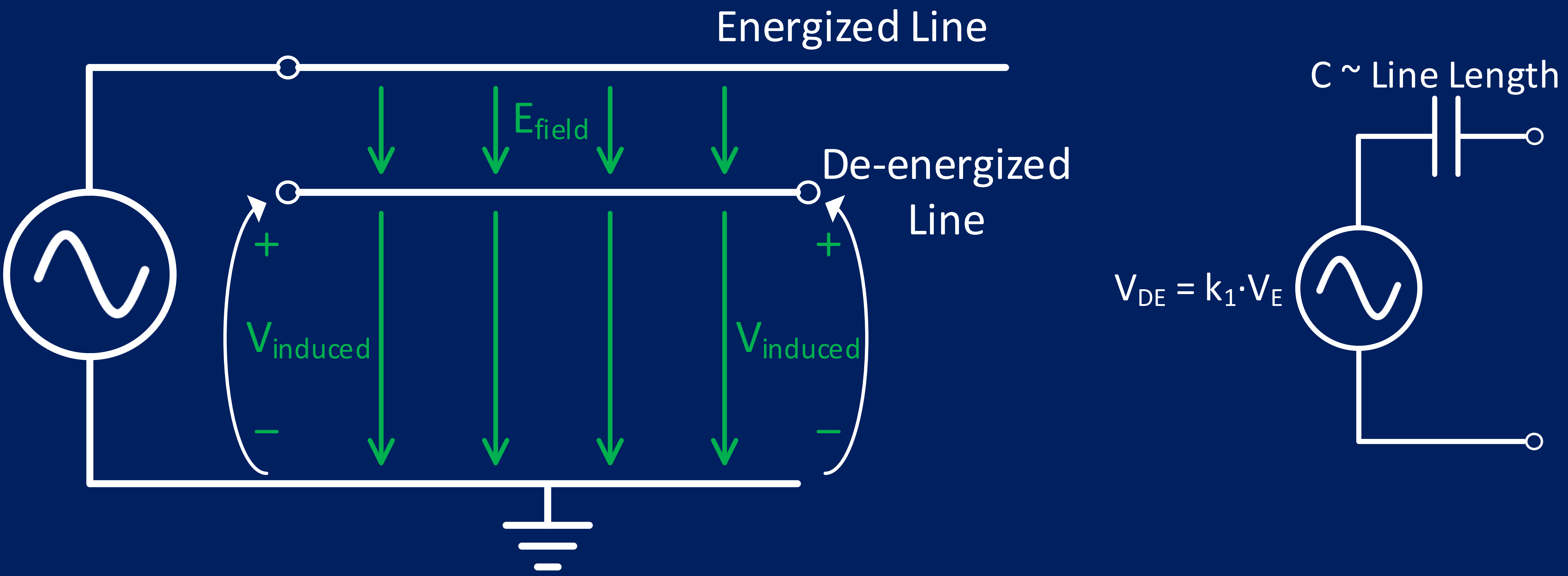
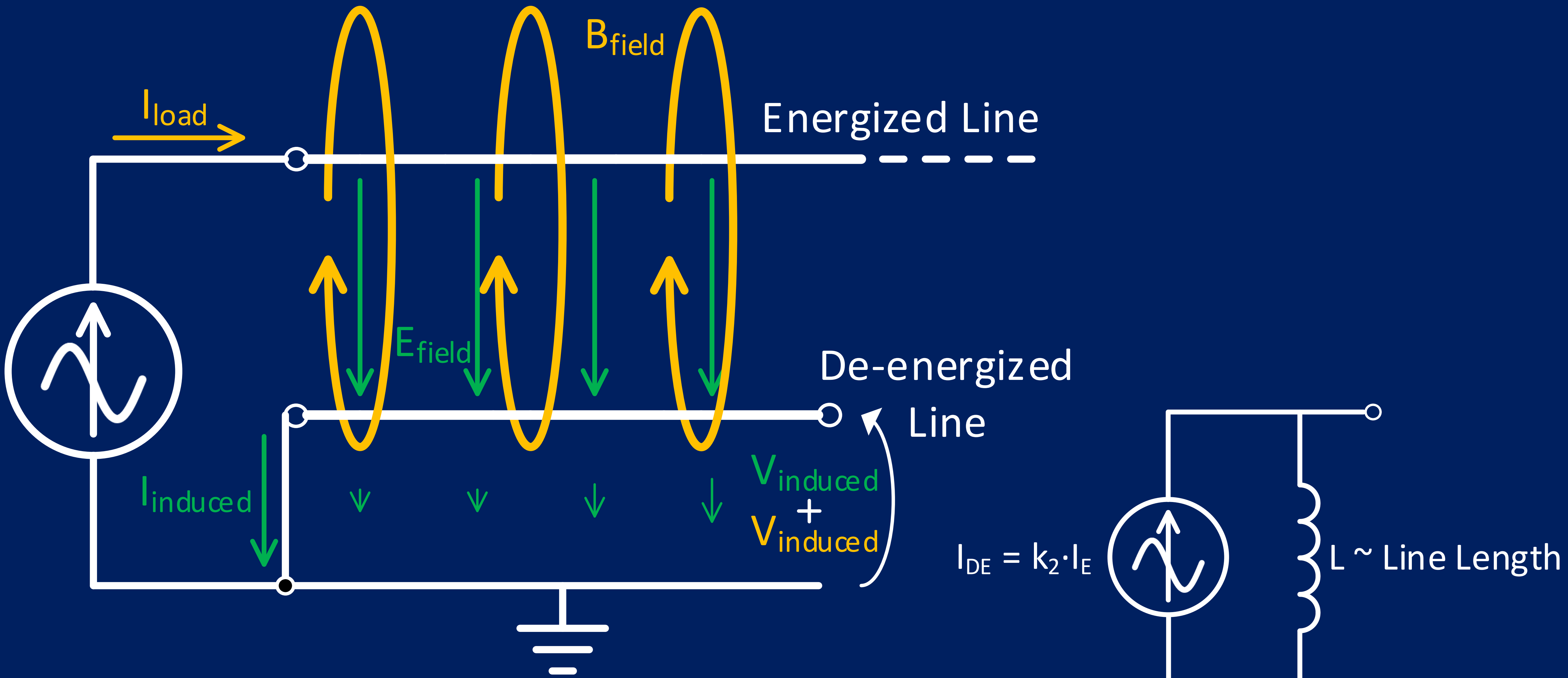
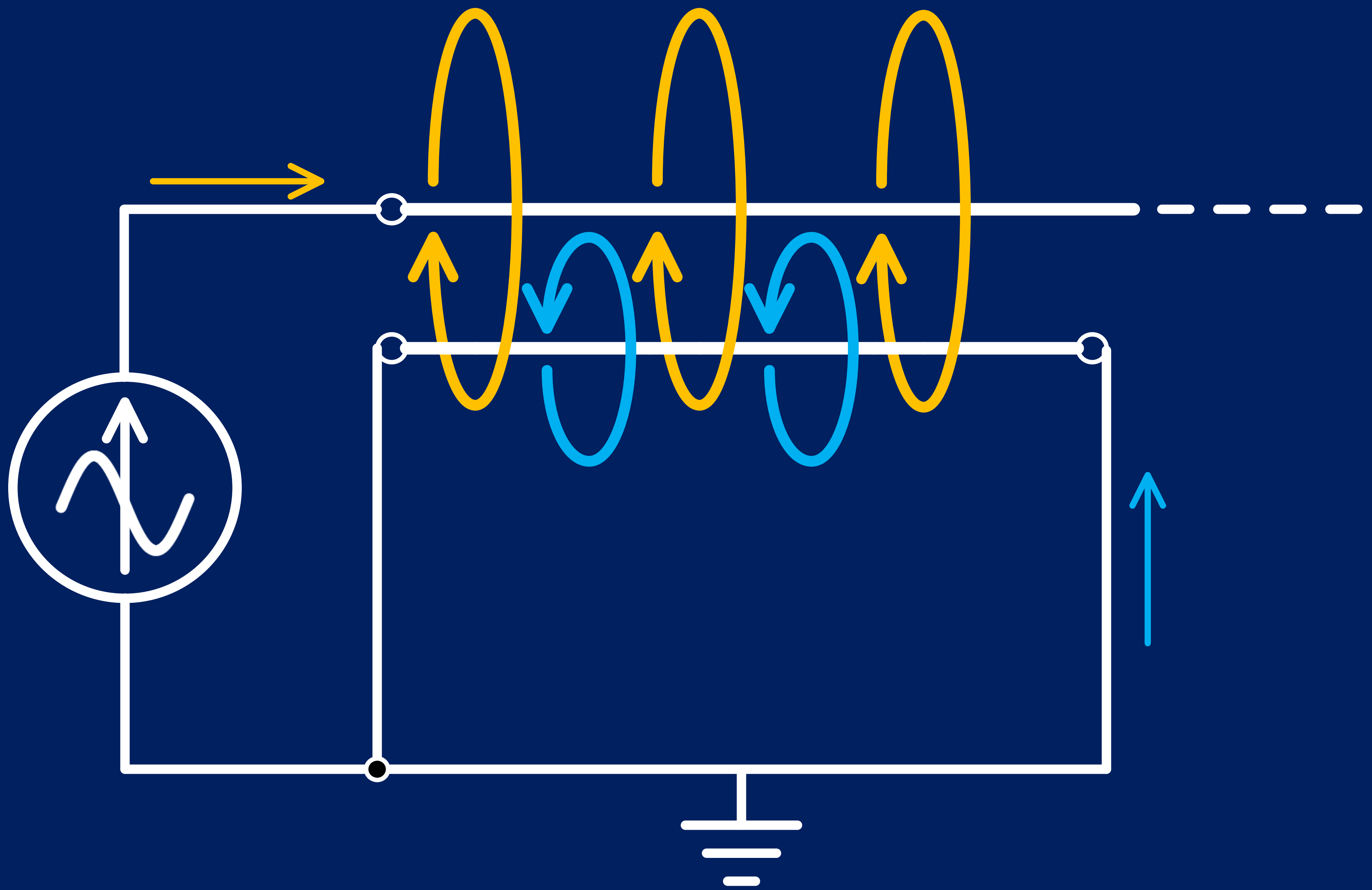
Ungrounded Transmission Line



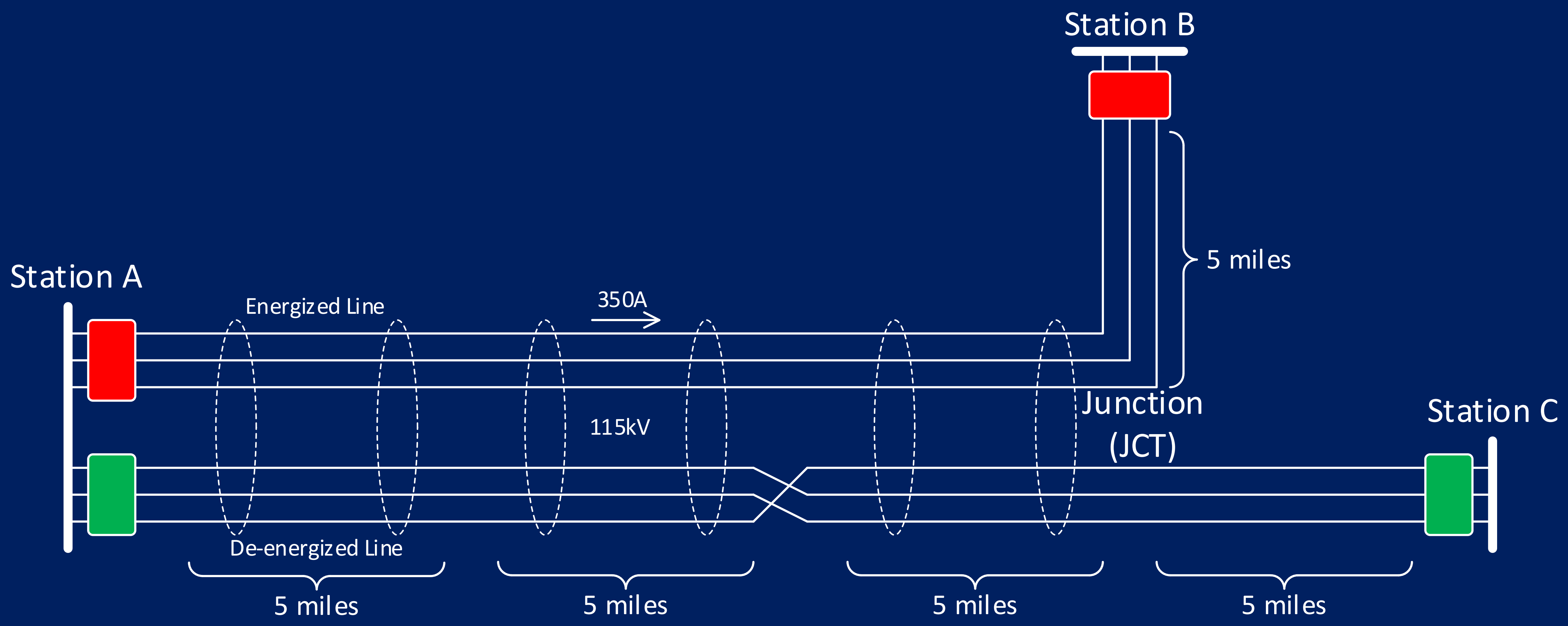
Transmission Line Grounding – Single Ground



Transmission Line Grounding – Multiple Grounds



Example: Double Circuit Line



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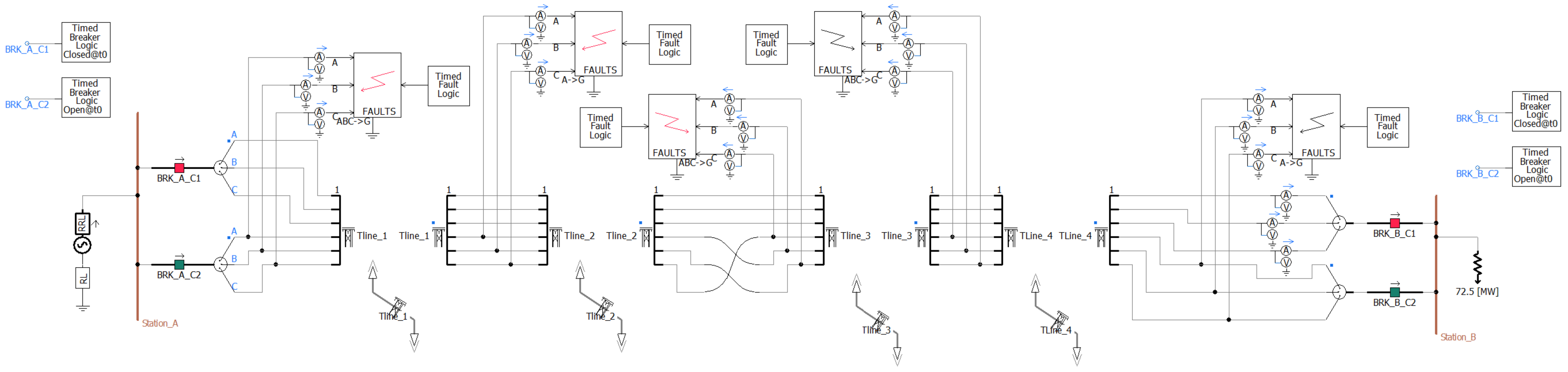
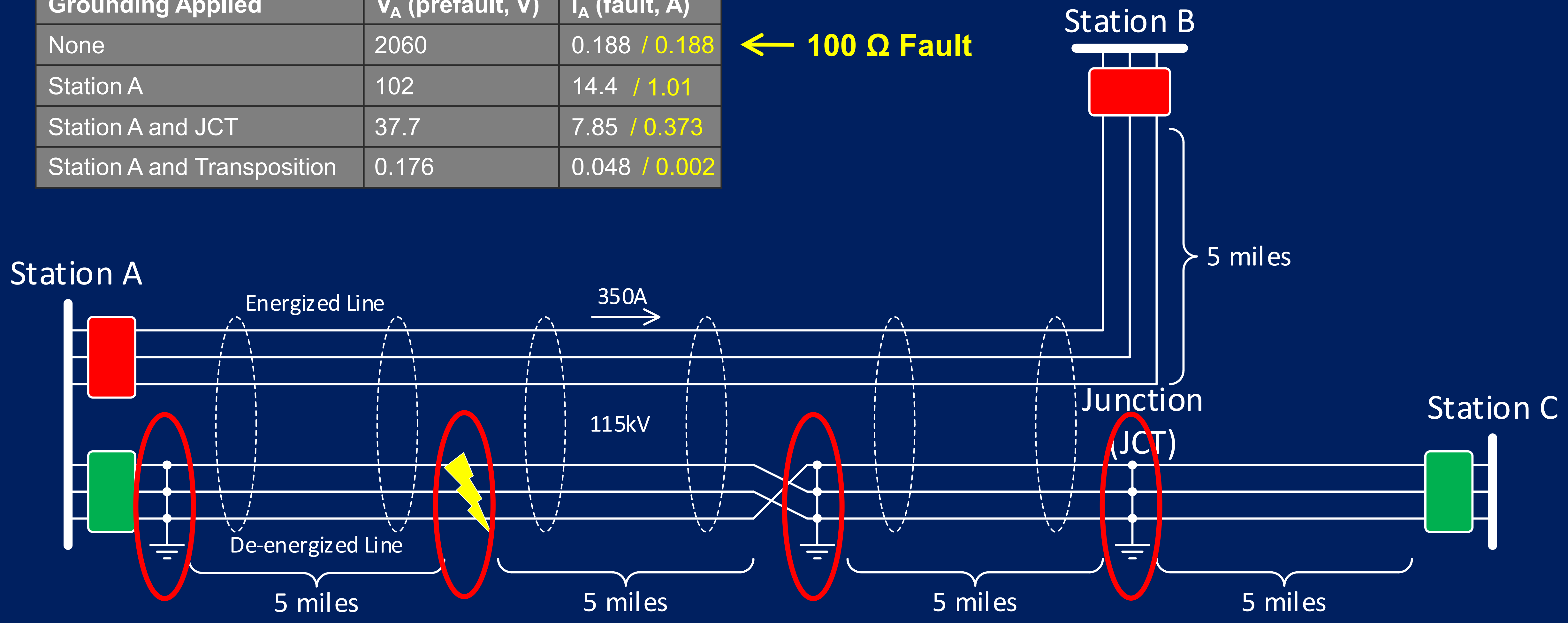


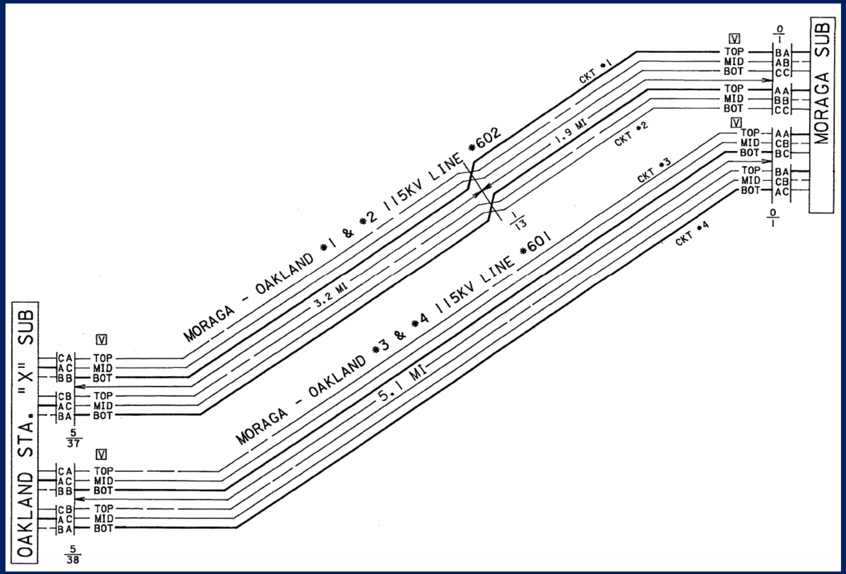
Example: Double Circuit Line

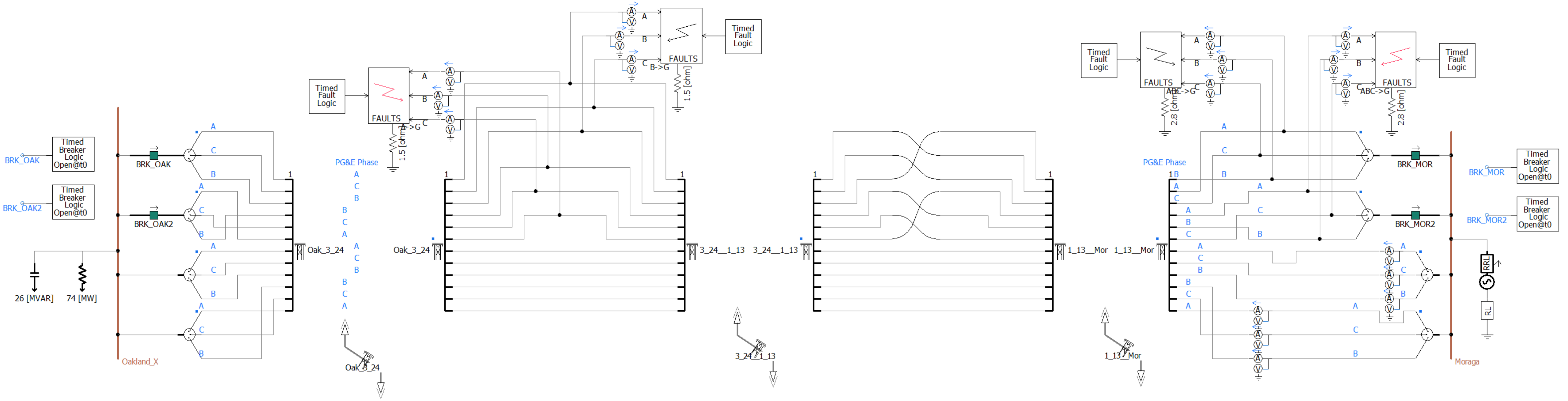
Grounding Applied	V_A (prefault, V)	I_A (fault, A)
None	2060	0.188 / 0.188
Station A	102	14.4 / 1.01
Station A and JCT	37.7	7.85 / 0.373
Station A and Transposition	0.176	0.048 / 0.002

← 100 Ω Fault



Field Testing and EMTP Simulations





Outline

Ungrounded Line

	Voltage (V)			Current (mA)		
Circuit 2	Top Phase	Middle Phase	Bottom Phase	Top Phase	Middle Phase	Bottom Phase
Tower 0/1 Field Test	722	825	400	16.7	18.6	9.9
Tower 0/1 Simulation	951.3	1275.1	544.9	19.9	26.5	19
Tower 3/24 Field Test	828	401	715	19	12	16
Tower 3/24 Simulation	1267.7	547.2	956.6	26.3	19.1	20

Grounded at Opposite Location

	Voltage (V)			Current (mA)		
Circuit 2	Top Phase	Middle Phase	Bottom Phase	Top Phase	Middle Phase	Bottom Phase
Tower 0/1 Field Test	29	33	13	800	1000	800
Tower 0/1 Simulation	6.2	7.6	8.6	821	1003.4	1133.5
Tower 3/24 Field Test	10	9	11.5	900	700	800
Tower 3/24 Simulation	7.8	8.7	6.3	1024.6	1152.6	833

Conclusion

- Documented cases of fires started by de-energized lines
- Grounding de-energized lines can reduce electrical energy and fire ignition risk
  - Fire risk at location of grounds
  - Electric field vs magnetic field induction
  - Uniformity of magnetic field profile along line
  - Effectiveness of grounds (resistance)
  - EMTP required for detailed analysis
- EMTP can achieve good approximation
- Faraday's Law preferred to KVL when un-lumping the enigmatic inductor

Questions/Comments?