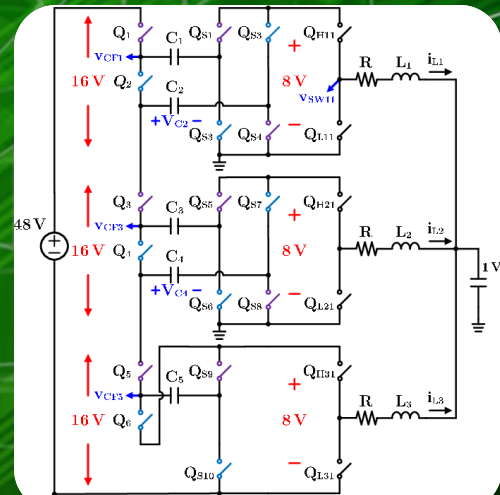


“A robot and a human talking about power electronics ...”



“A switched-capacitor dc-dc converter with series-input and parallel-output ...”



Power Electronics Turing Test: A Path Toward Strong AI in Power Electronics

Minjie Chen and Dak C. Cheng

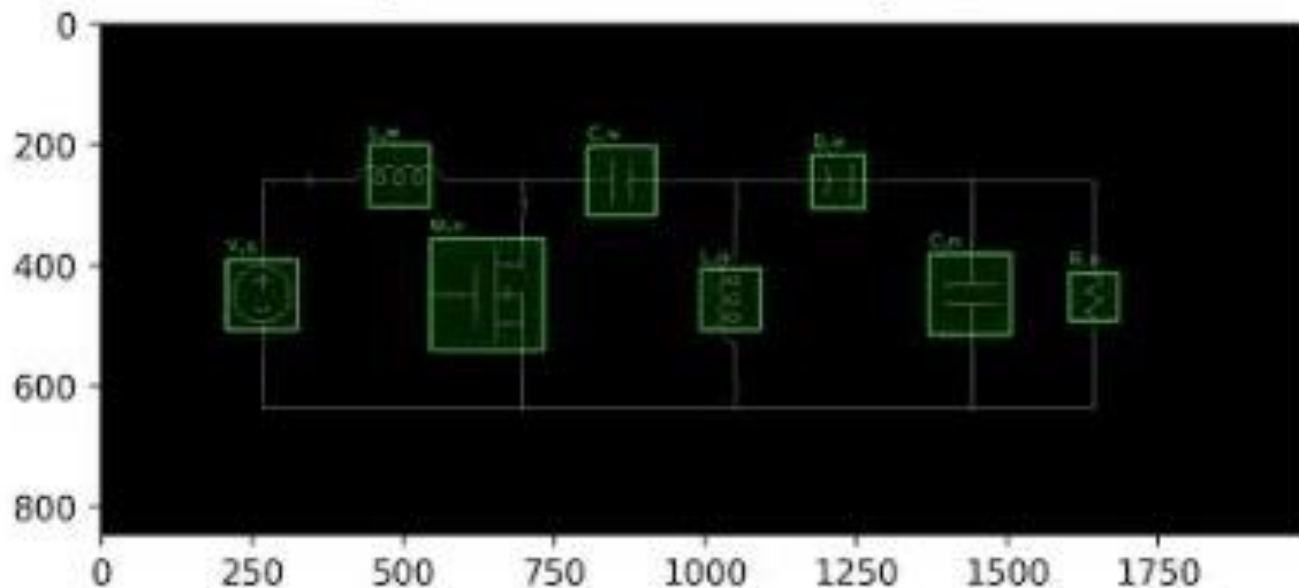
Princeton University

Recording from Dak Cheng (Princeton ECE'25 Undergrad)



Dak Cheng
Princeton Undergrad

Output of Machine Learning Classifier



https://www.youtube.com/watch?v=Q_nJV8klBtk



Strong AI and Domain-Specific AI ...



Artificial narrow
intelligence (ANI)

“AI as a Tool”



Artificial general
intelligence (AGI)

“General Purpose AI”



Artificial super
intelligence (ASI)

“Domain Specific AI”

- Image Recognition
- Speech Recognition
- Alpha - Go

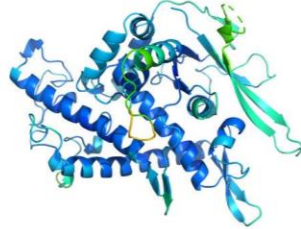
- ChatGPT - Language
- Sora - Vision
- GitHub Copilot – Logic Thinking

- Medicine Expert
- Materials Expert
- **Power Electronics?**

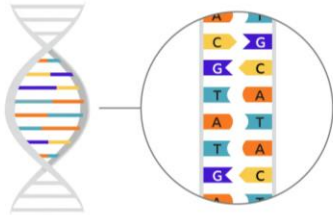
Power Electronics + AI?

- Is ***Strong*** AI ready to learn **Power Electronics**? - **Yes?**
- Is **Power Electronics** ready for ***Strong*** AI? - **No?**

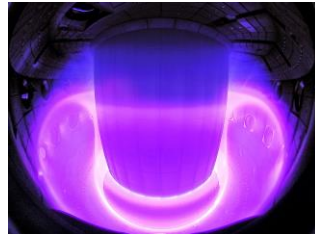
AI for Protein Prediction



AI for DNA Sequencing



AI for Fusion Control



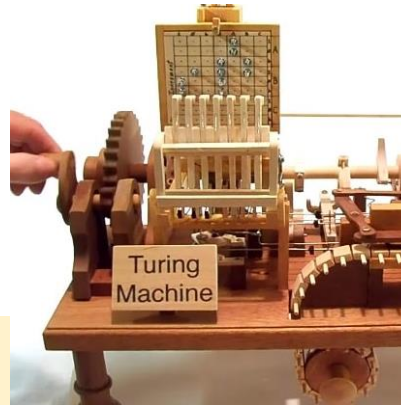
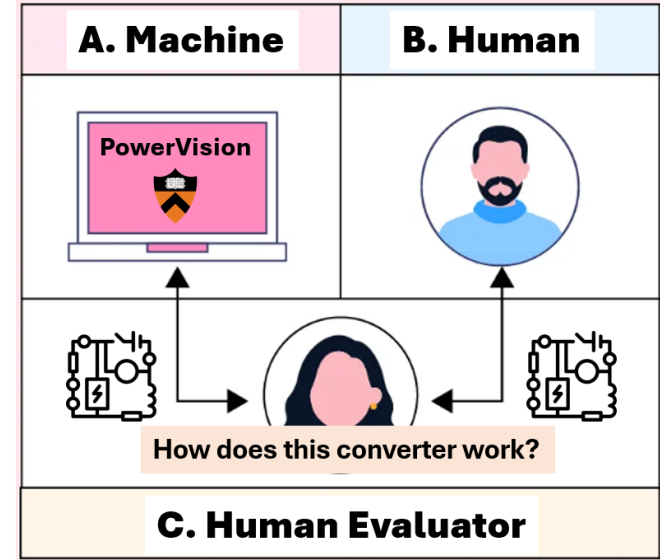
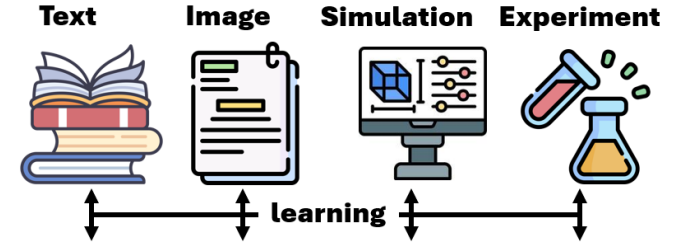
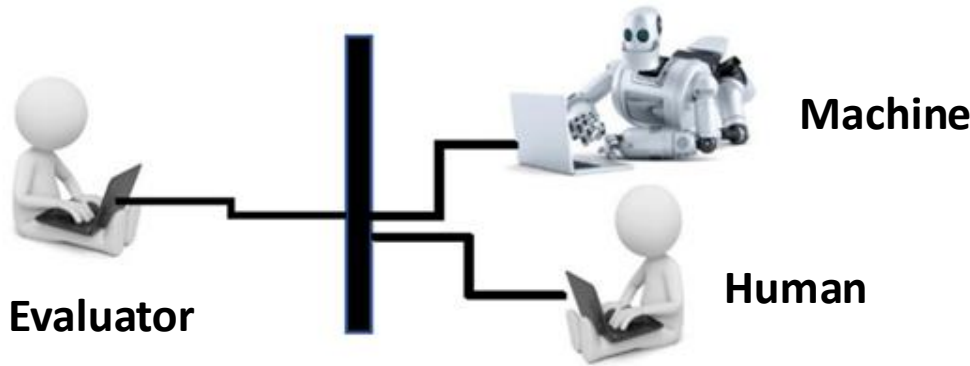
“Once data is ready, AI is ready!”

“Once question is ready, solution is ready!”

“How does human understand power electronics?”

“How does machine understand power electronics?”

Turing Test in Power Electronics?



Dr. Alan Turing (born June 23, 1912)
 PhD in math, Princeton
 A. M. TURING, "I.—COMPUTING MACHINERY AND INTELLIGENCE," *Mind*, vol. LIX, no. 236, pp. 433–460, 10 1950.

Teach AI to Understand Power Electronics?

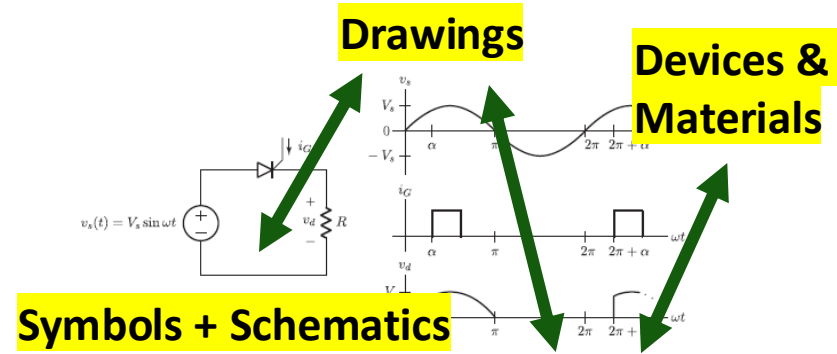
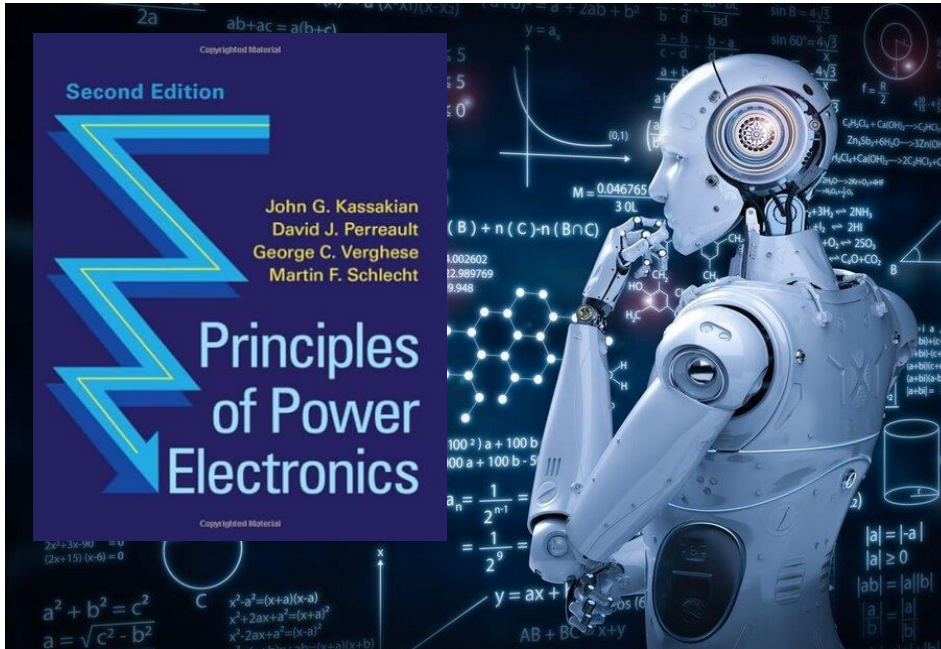


Figure 4.1 Half-wave phase-controlled rectifier with resistive load and its associated waveforms.

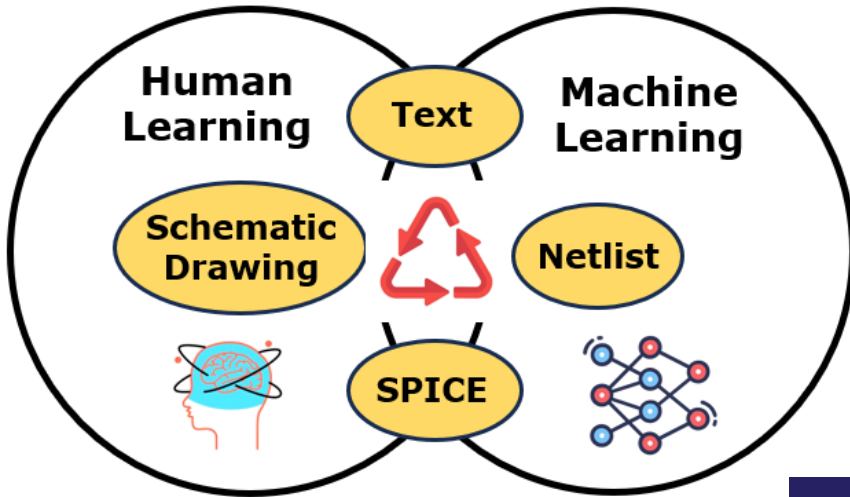
current pulse (whose width is not critical) applied once every cycle of the line voltage waveform. The SCR is regenerative device, that is, once it is on, it remains on — even after the gate pulse ends — until its anode current goes to zero (which in this circuit occurs at the zero-crossing of the ac input voltage). The angle α is variously called the *firing angle*, the *angle of retard*, or the *delay angle*. Retard or delay is measured relative to the angle at which the device would have turned on if it were a diode. The resulting output voltage v_d is shown in Fig. 4.1, and from it we can infer the effect of gate control. The important parameter of the rectifier is its dc component:

$$\langle v_d \rangle = \frac{V_s}{2\pi}(1 + \cos \alpha) = \frac{V_{do}}{2}(1 + \cos \alpha)$$

where V_{do} , the maximum possible value of $\langle v_d \rangle$, is also the output of an equivalent diode rectifier. The voltage $\langle v_d \rangle$ as a function of α is known as the *control characteristic* of the rectifier and is shown in Fig. 4.2.

Page 81 of KPSV Textbook

Prepare Data for Massive Automated Learning ...



We can obtain a simpler alternative by making the inductor value $1/\tau = R/L$. Placing this pole at a frequency yields an inductor (and resistor) I_{dc} . But the current in the ac source, which is undesirable for reasons we wish to eliminate all but the fundamental

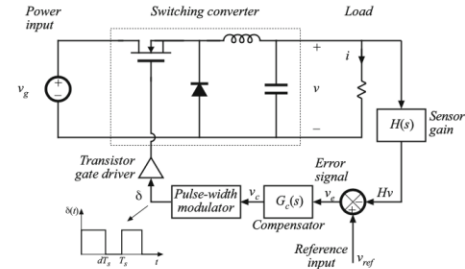
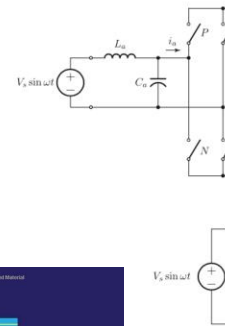


Fig. 1.11 Addition of control system to regulate the output voltage

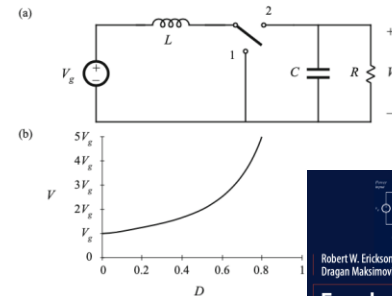


Fig. 1.12 The boost converter: (a) ideal converter circuit, (b) output voltage

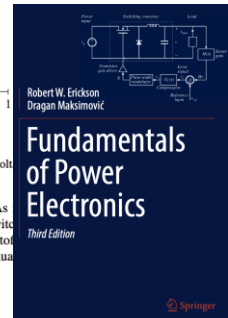
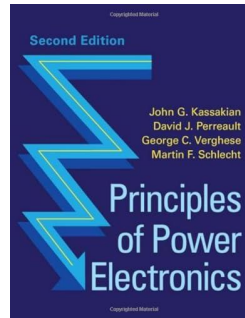
Figure 1.13a illustrates a simple dc-to-ac inverter circuit. As the switch duty cycle is modulated sinusoidally, this causes the switch to pass the desired low-frequency components of $v_g(t)$, but to attenuate

ac/dc converter topology on the dc side and a second and more effective

the ac/dc converter in the preceding circuit. The average current i_a by the switches to the inverter strongly influence the form of the ac filter. In this case the ac source, v_{ac} , which ideally has an incremental impedance of zero at any frequency. Therefore a shunt filter alone will not work, and the filter topology must

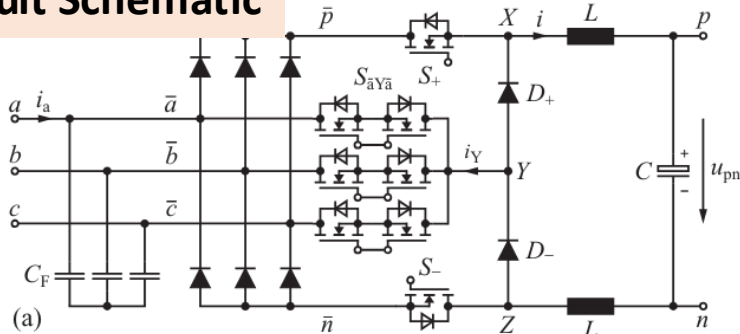
IEEE TRANSACTIONS ON POWER ELECTRONICS

A PUBLICATION OF THE IEEE POWER ELECTRONICS SOCIETY

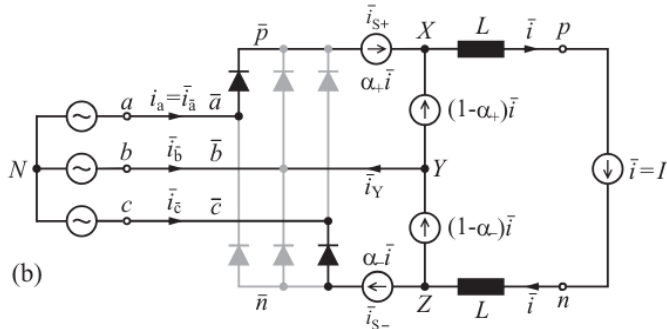


Structured Abstraction in Power Electronics

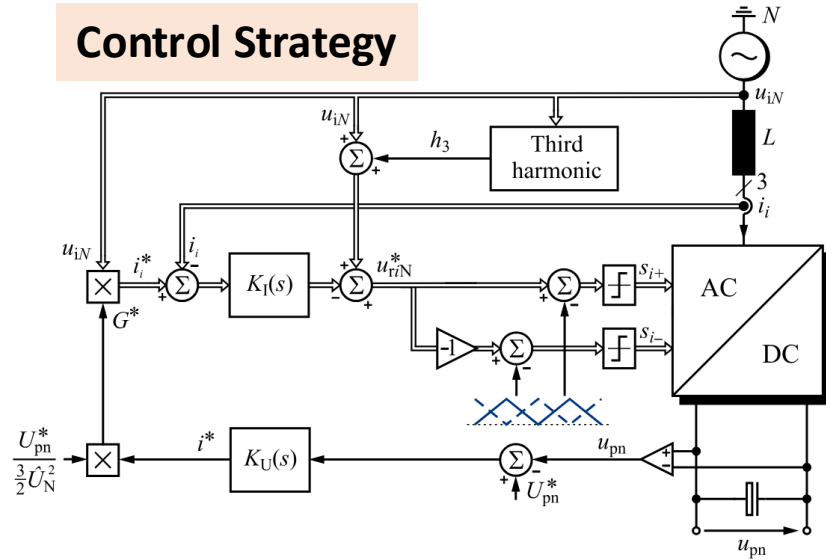
Circuit Schematic



Conceptual Abstract



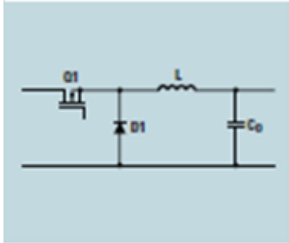
Control Strategy



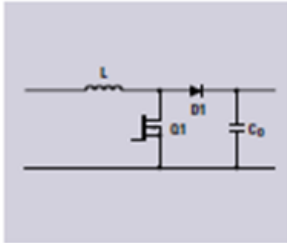
- J. W. Kolar and T. Friedli, "The Essence of Three-Phase PFC Rectifier Systems—Part I," in *IEEE Transactions on Power Electronics*, vol. 28, no. 1, pp. 176-198, Jan. 2013.
- T. Friedli, M. Hartmann and J. W. Kolar, "The Essence of Three-Phase PFC Rectifier Systems—Part II," in *IEEE Transactions on Power Electronics*, vol. 29, no. 2, pp. 543-560, Feb. 2014.

Teach AI to understand/classify Basic Schematics?

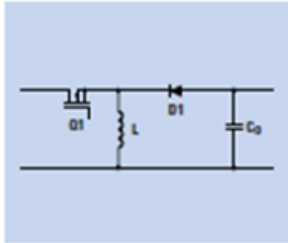
Buck



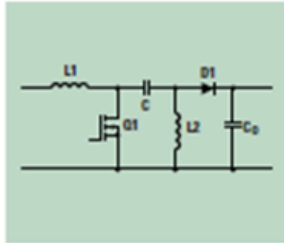
Boost



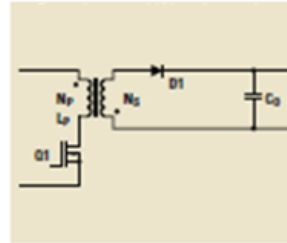
Buck Boost



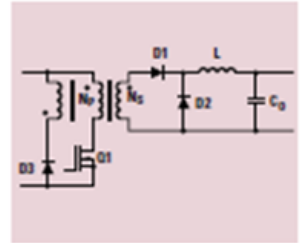
SEPIC



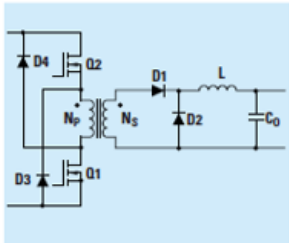
Flyback



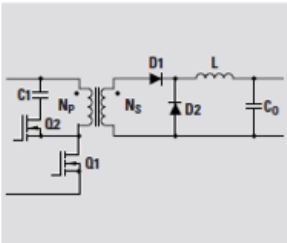
Forward



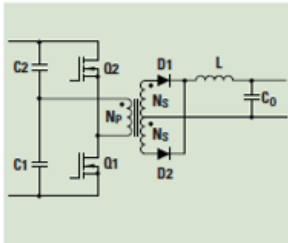
2 Switch Forward



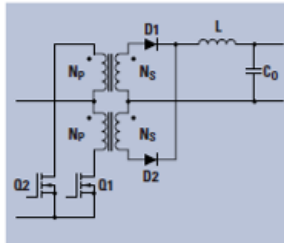
Active Clamp Forward



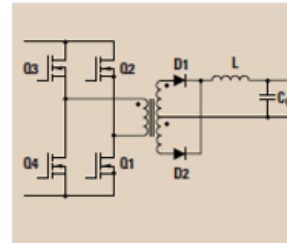
Half Bridge



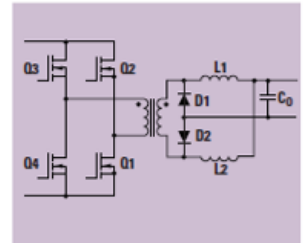
Push Pull



Full Bridge



Phase Shift ZVT



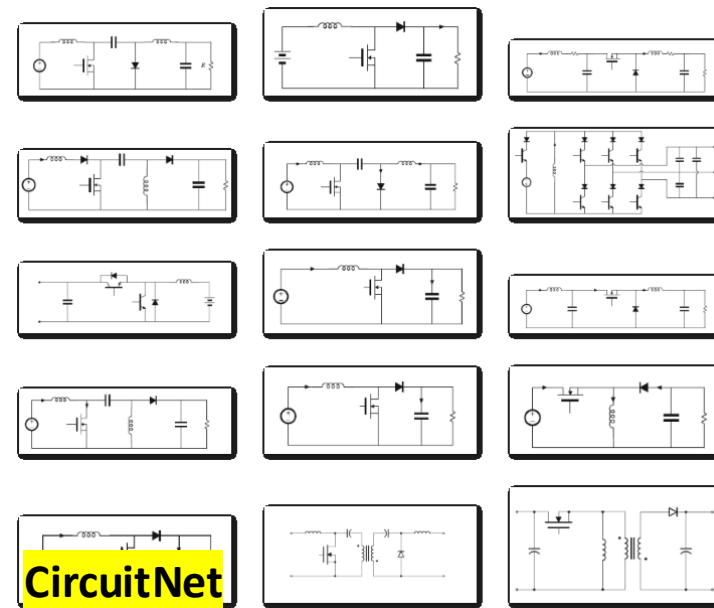
- 90% of power electronics in use are designed following these topologies
- 90% of power electronics designs already “exist” and are just “fine-tuning” efforts
- Texas Instruments power topology catalog: <https://www.ti.com/lit/ml/sluw001g/sluw001g.pdf>

Training Data Preparation



ComponentNet

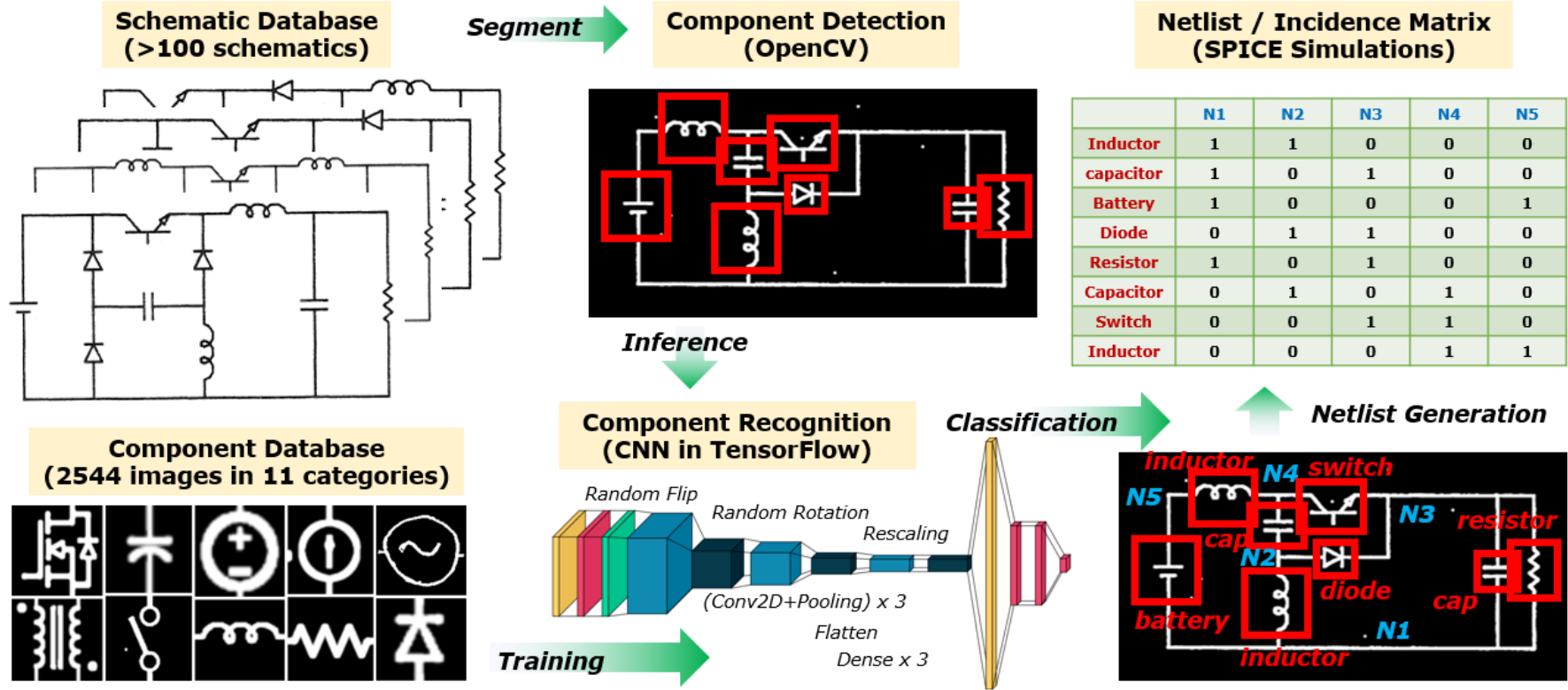
- 2544 hand-collected component images
- Machine-drawn and hand-drawn
- Semiconductor switches, capacitors, magnetics, controllers, labels, symbols



- 200 hand-classified schematics
- Machine-drawn and hand-drawn

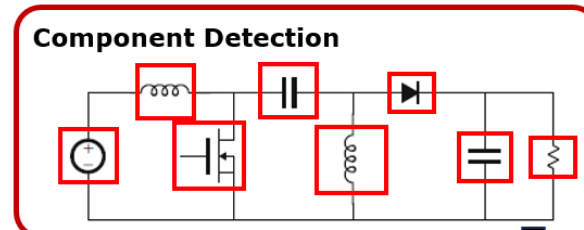
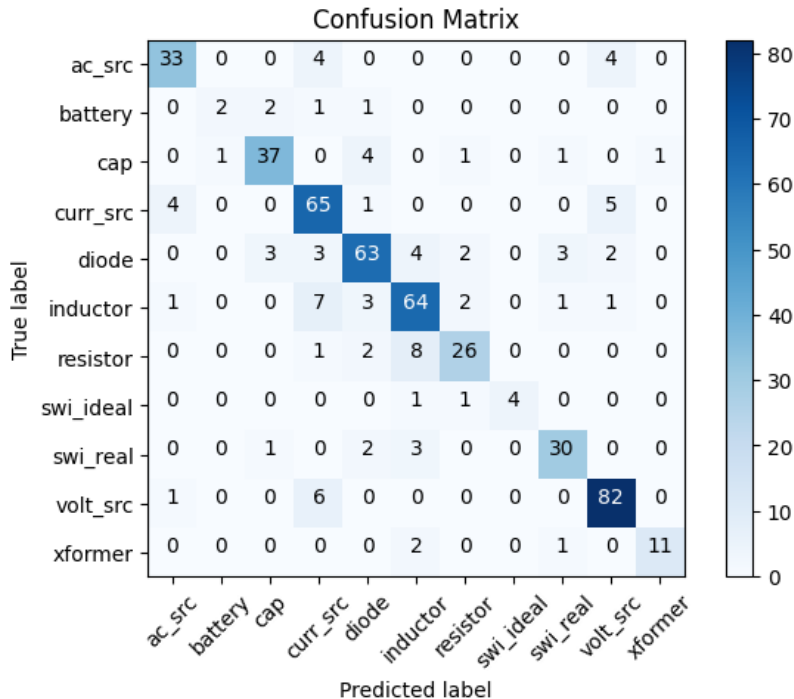
Open-Sourced: <https://github.com/minjiechen/PowerVision>

NetlistMaker – Convert Schematics to Netlists

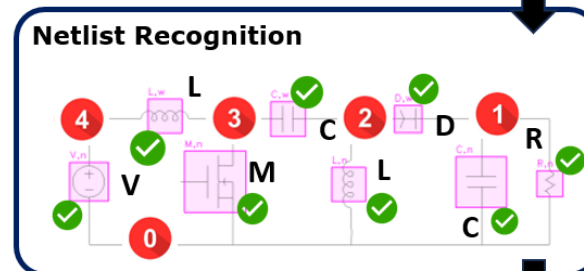


Performance of the NetlistMaker

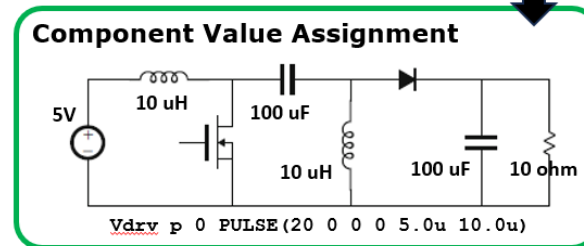
>90% accuracy for component classification



>90%



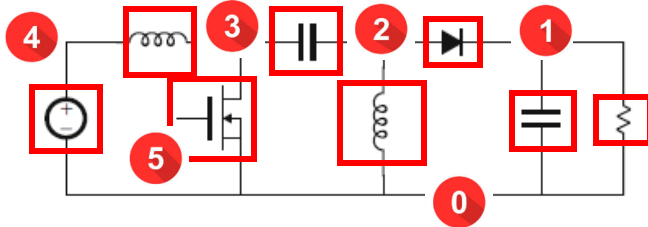
<70%



Hand-Assisted

Advanced Understanding about the Schematic

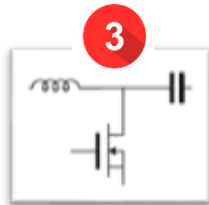
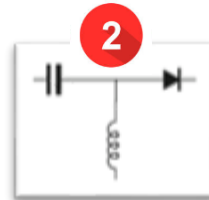
Circuit Schematic



Incidence Matrix

	N_0	N_1	N_2	N_3	N_4	N_5
R	2	1	0	0	0	0
C	2	1	0	0	0	0
V	2	0	0	0	1	0
L	2	0	1	0	0	0
M	3	0	0	1	0	2
L	0	0	0	2	1	0
D	0	2	1	0	0	0
C	0	0	2	1	0	0

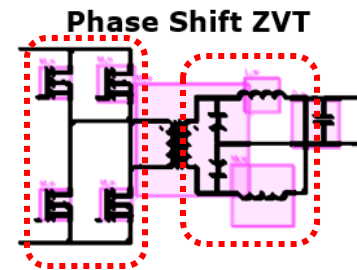
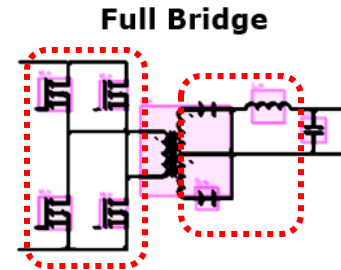
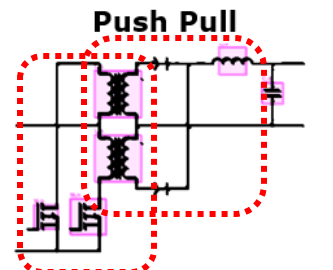
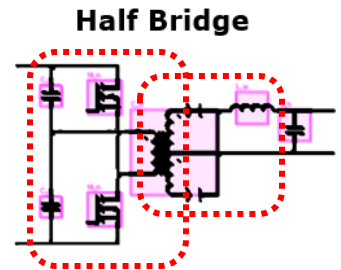
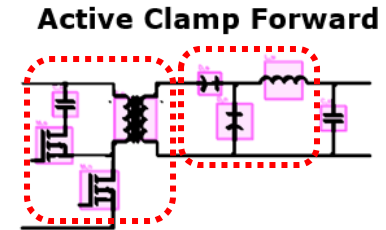
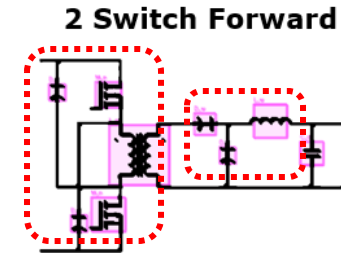
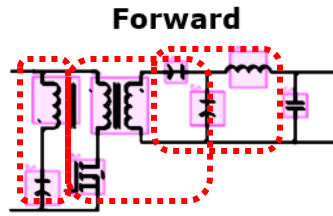
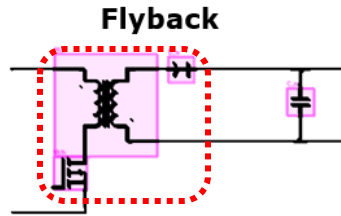
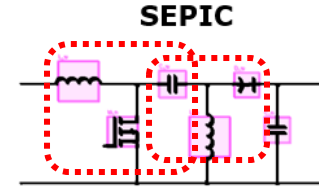
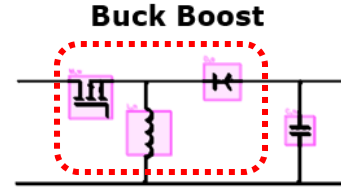
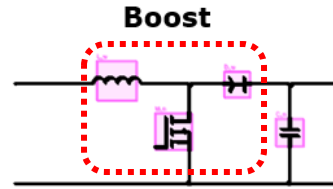
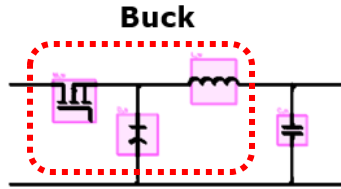
Key Patterns



Matrix Patterns <-> Circuit Functions

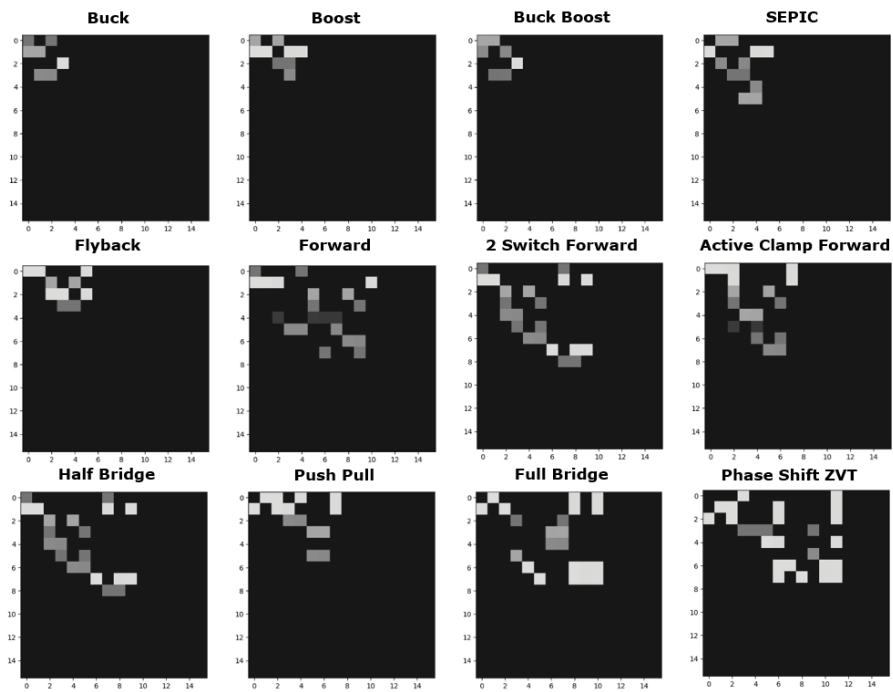
N	0	1	2	3	4	5
R						
C						
V						
L						
M						
L						
D						
C						

Train on a Large Number of Pre-Labelled Circuits

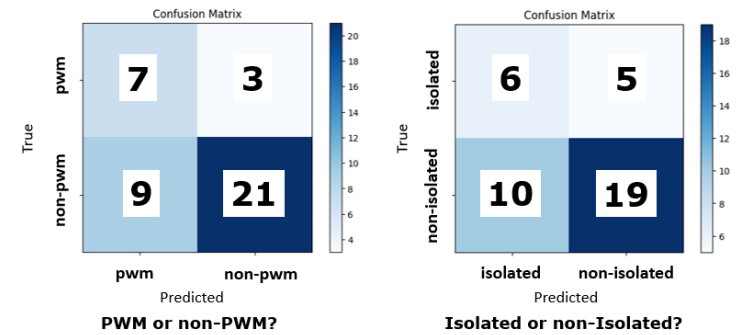


A Failed Turing Test, but A Successful First Attempt ...

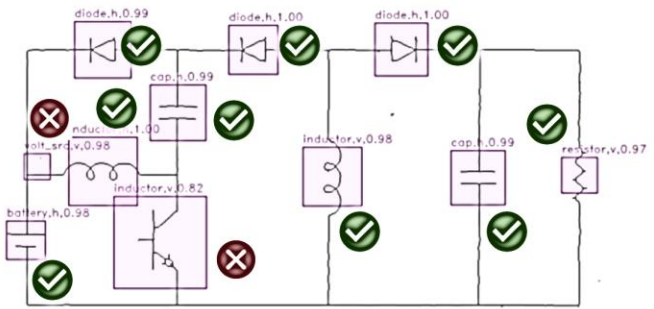
Power Electronic Topology “Fingerprints”



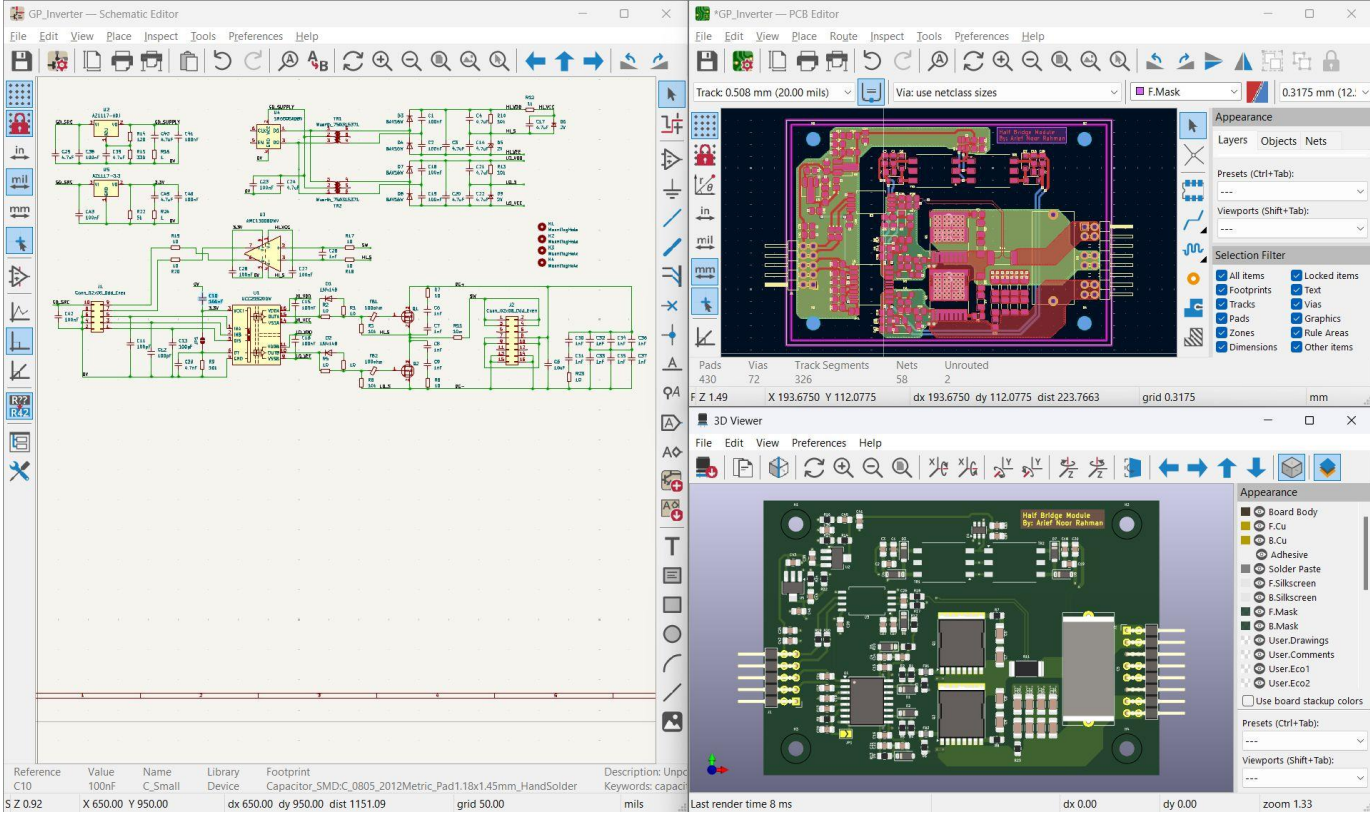
Classify and explain an existing circuit topology



Try to interpret a new, unknown circuit topology

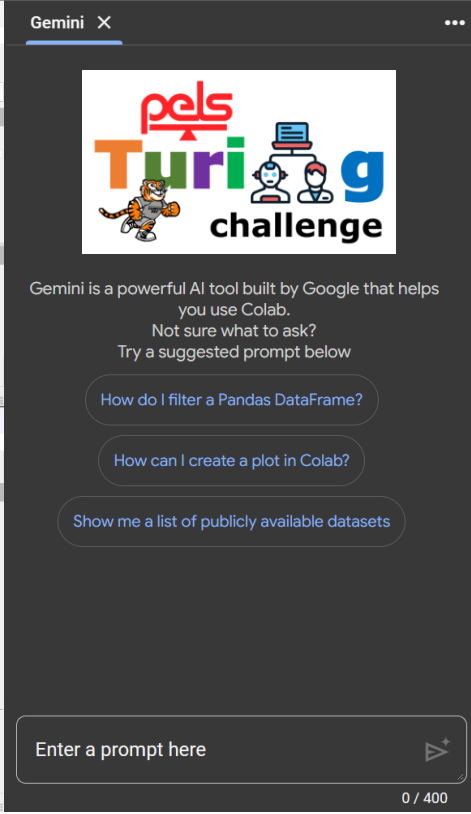


End-to-End Cognitive Intelligence beyond Schematics



The image displays three windows from the Altium Designer software:

- Schematic Editor:** Shows a detailed circuit schematic for a GP_Inverter. It includes various components like resistors, capacitors, and integrated circuits, connected by traces. A legend on the right indicates different types of components.
- PCB Editor:** Shows a top-down view of the PCB layout. It features a grid, tracks, vias, and pads. The track width is set to 0.508 mm (20.00 mils) and the via diameter is 0.3175 mm (12 mils). A status bar at the bottom shows statistics: Pads: 430, Vias: 72, Track Segments: 326, Nets: 58, Unrouted: 2.
- 3D Viewer:** Shows a 3D perspective view of the PCB. It includes a legend for various layers and materials, such as Board Body, F.Cu, B.Cu, Adhesive, Solder Paste, S.Silkscreen, F.Silkscreen, F.Mask, B.Mask, User Drawings, User Comments, User Eco1, and User Eco2.



The Gemini AI interface is shown with the following elements:

- Header:** "Gemini" with a close button.
- Image:** A logo for the "pels Turing challenge" featuring a tiger and two people icons.
- Text:** "Gemini is a powerful AI tool built by Google that helps you use Colab. Not sure what to ask? Try a suggested prompt below"
- Prompts:** Three suggested prompts in rounded rectangles:
 - How do I filter a Pandas DataFrame?
 - How can I create a plot in Colab?
 - Show me a list of publicly available datasets
- Input Field:** "Enter a prompt here" with a send button.
- Footer:** "0 / 400" characters remaining.

What is the true Artificial Intelligence in Power Electronics?

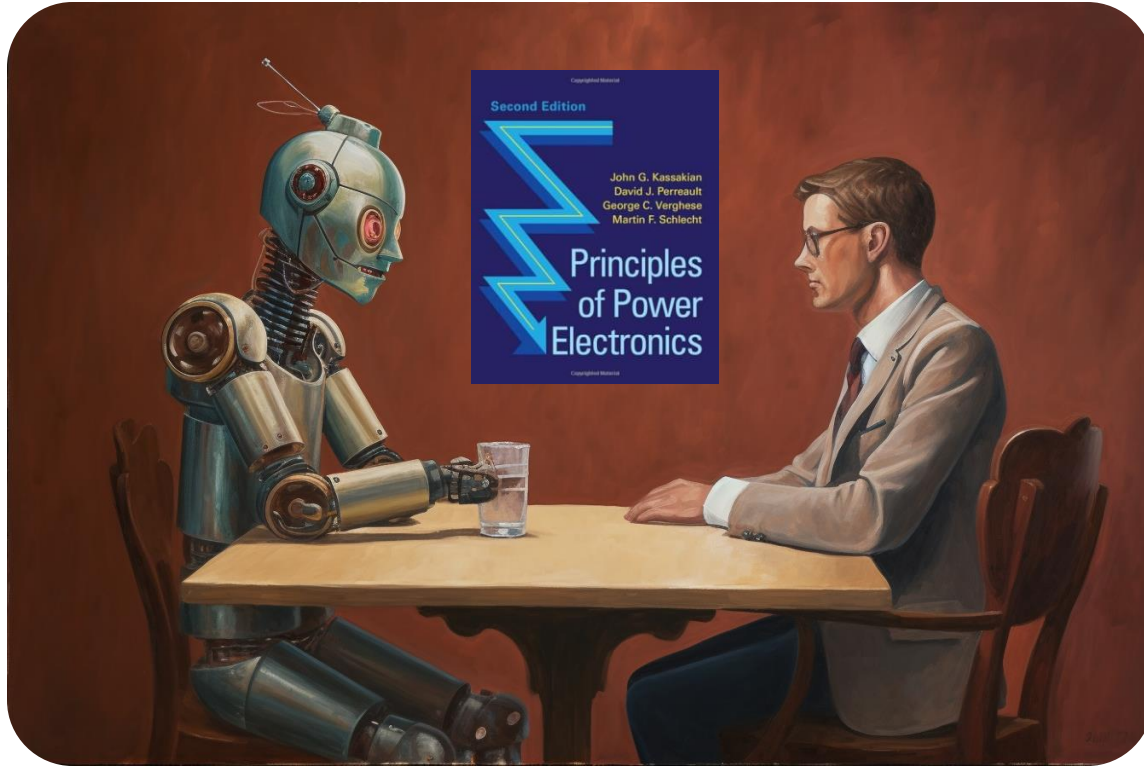


Image + Language

≠

General
Intelligence

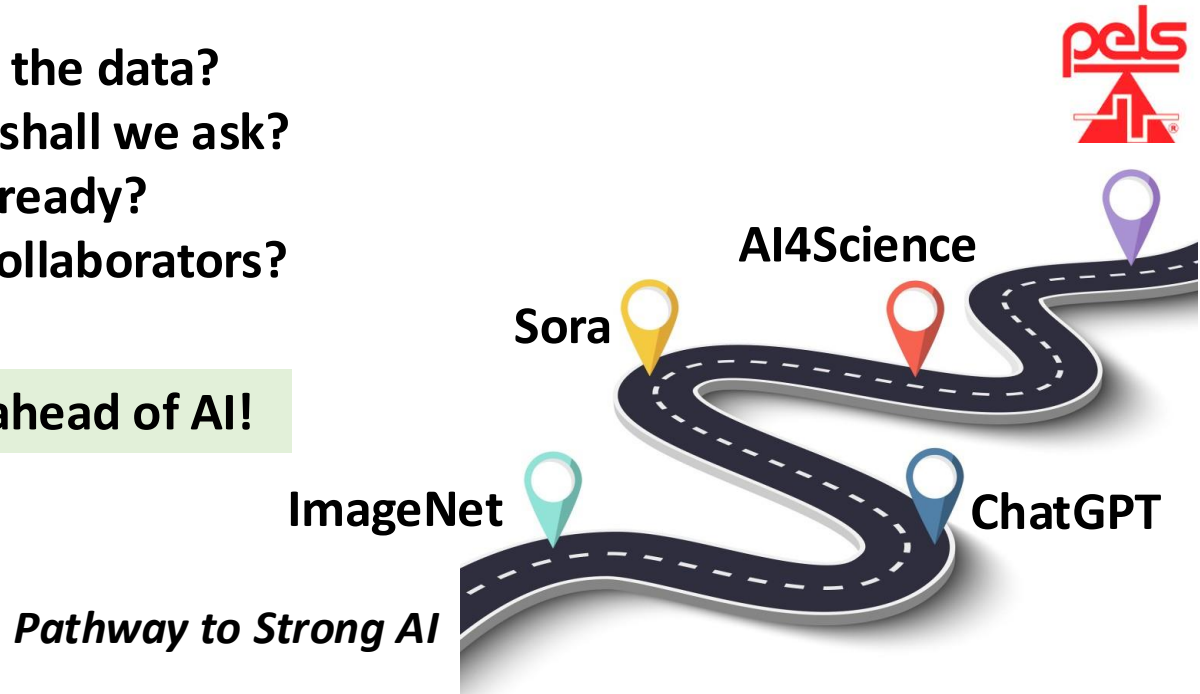
≠

Domain-Specific
Intelligence

COMPEL community should think ahead of AI !!!

- How to enable AI to pass Power Electronics Turing Test?
 - Where is data?
 - How to organize the data?
 - What questions shall we ask?
 - Which tools are ready?
 - Where are our collaborators?
 - Who cares?

Embrace and think ahead of AI!



A Path Toward Strong AI in Power Electronics

- Most human-created information documented/processed as 1-D time sequences (natural language) or 2-D arrays (computer vision).
- Most advanced AI models focus on **language** or **vision** processing.
- Convert interesting power electronics problems into time sequence (language) or vision (image) problems.
- Create the database → migrate the tools → build an open-source community → advance the field collaboratively and competitively



time-sequence processing (NLP)

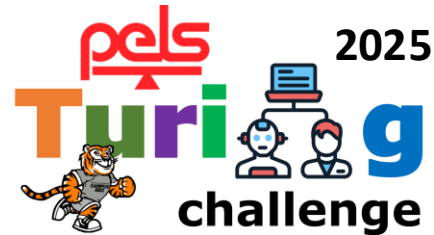
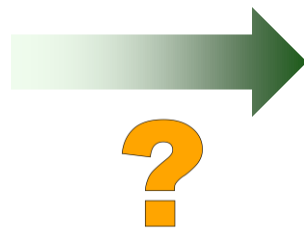



image processing (computer vision)

Rethinking Human and Machine in Power Electronics


COMPEL 2002

2002 IEEE Workshop on
**Computers in
Power Electronics**

Proceedings
June 3-4, 2002
University of Puerto Rico at Mayagüez

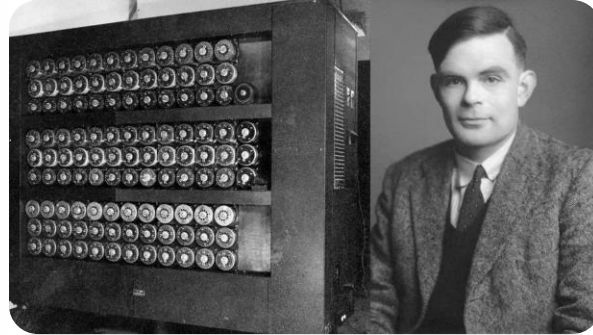


IEEE

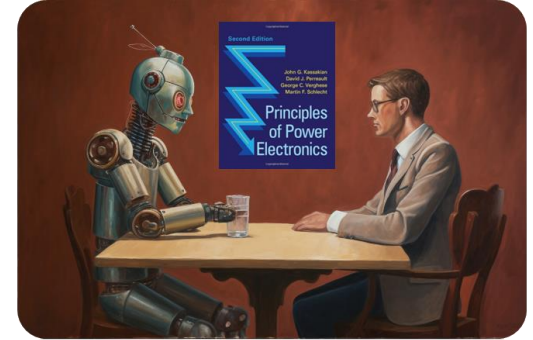


PELS
IEEE Power Electronics Society

IEEE Catalog Number: 02TH8633



Turing and His Machine



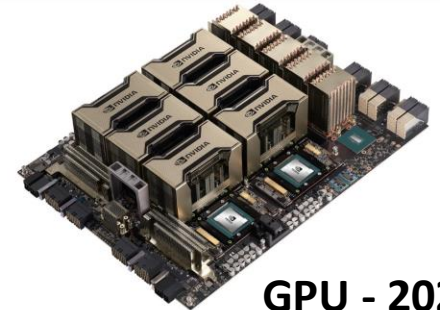
Power Electronics & AI



ENIAC - 1945



PC - 1980



GPU - 2024