2nd IEEE International Challenge in Design Methods for Power Electronics

2025 PELS MagNet Challenge

MagNet Challenge 2

Kickoff Meeting, January 5, 2025

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MagNet 2025 Organizing Team
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IEEE pels MagNetX Challenge 2

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A Successful MagNet Challenge 1 in 2023

MagNet Challenge for Data-Driven Power Magnetics Modeling

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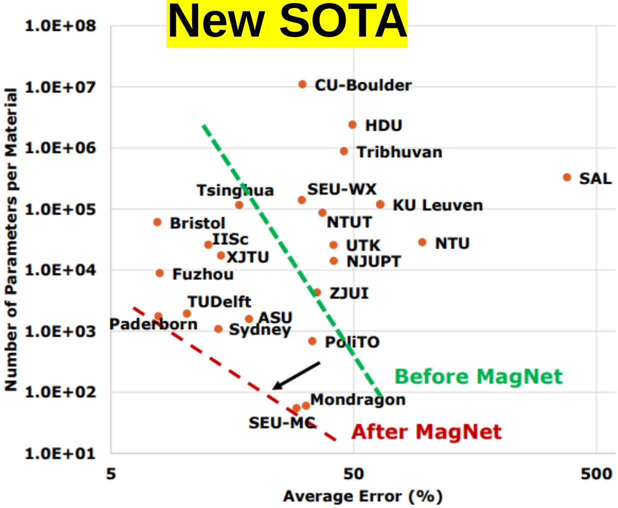
133 co-authors

Charles Steinmetz (1865-1923)

New SOTA



- Arizona, USA
- Fuzhou, China
- Hangzhou, China
- Bangalore, India
- Leuven, Belgium
- Hernani, Spain
- Nanjing, China
- Cambridge, USA
- Singapore, Singapore
- Taipei, Taiwan
- Hong Kong, China
- Paderborn, Germany
- Princeton, USA
- Hanover, USA
- Piscataway, USA
- Torino, Italy
- Graz, Austria
- Lalitpur, Nepal
- Beijing, China
- Fremont, USA
- Delft, Netherland
- Bristol, UK
- Zurich, Switzerland
- Boulder, USA
- Santa Clara, USA
- Manchester, UK
- Sydney, Australia
- Knoxville, USA
- Xi'an, China
- Mountain View, USA

MagNet 2023 - IEEE International Challenge in Design Methods for Power Electronics

24 teams

Many thesis

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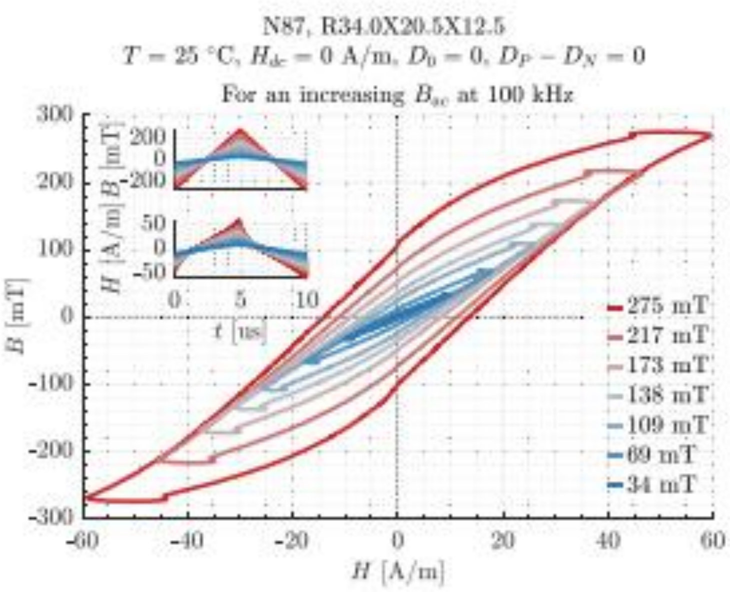
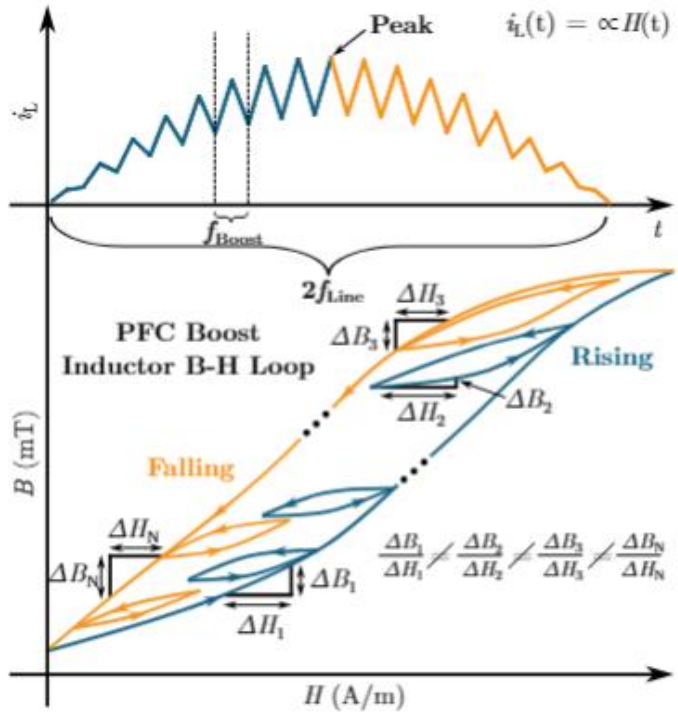
MagNet 2025 – Transient Challenge





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2025: from Racetrack to Open Fields

pels MagNet challenge

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MagNet 2025 – Transient Challenge

MagNet 2023 Chair:

- Shukai Wang, Princeton, USA
- Hyukjae Kwon, Princeton, USA
- Haoran Li, Princeton, USA

Organizing Committee:

- Minjie Chen, Princeton, USA
- Charles Sullivan, Dartmouth, USA
- Thomas Guillod, Dartmouth, USA
- Oliver Wallscheid, Paderborn, Germany
- Sinan Li, Sydney, Australia
- Han Cui, Tianjin, China

Judge Committee:

- Charles Sullivan, Dartmouth, USA
- David Perreault, MIT, USA
- Johann Kolar, ETH Zurich, Switzerland
- Dragan Maksimovic, CU Boulder, USA
- SY Ron Hui, NTU, Singapore

Task #1: NEXT B-H Step Estimation

- Sequence to scalar model
- Predicting next step only
- Tiny model
- Refreshing past data
- E.g., predicting μ_{eff}

Task #2: FULL Trajectory Estimation

- Sequence to sequence model
- Predicting a long sequence
- Large model
- Accumulate predicting error
- E.g., predicting a full PFC cycle

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Strategy to win the Challenge?

- **Understand physics and understand data**
  - Model / method should be reasonably explainable
  - Balancing model generality and model accuracy
- **Understand materials and understand design**
  - What manufacturers provide? – modeling framework
  - What designers need? – software engineering
- **Respect legacy and challenge legacy**
  - Understand what has been done
  - Challenge existing understanding
  - Leverage modern methods and tools
- **Winning team structure:**

Data Science

Power Electronics

Software Engineering

Magnetics

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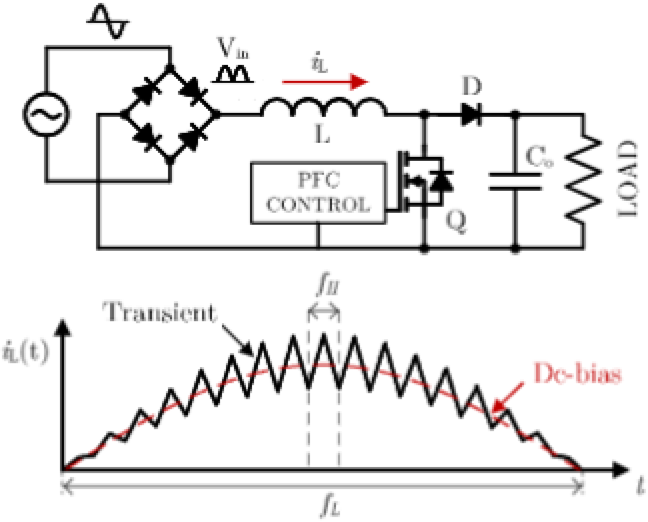
Motivation for MagNet Challenge 2

- No good method to design magnetics in transient.
- **Imprecise material ↔ imprecise model ↔ imprecise design.**
- Unnecessary design margins (thermal, B_{sat}, batch-to-batch variation, …).
- Future chips, vehicles, and robotics need miniaturization and precision.
- Opportunities to reduce the size of all magnetics by 20%~50%?
- Need a better way to document, compress, and share information.
- Help the manufacturers to improve repeatability, control the quality, and share better data in better ways.

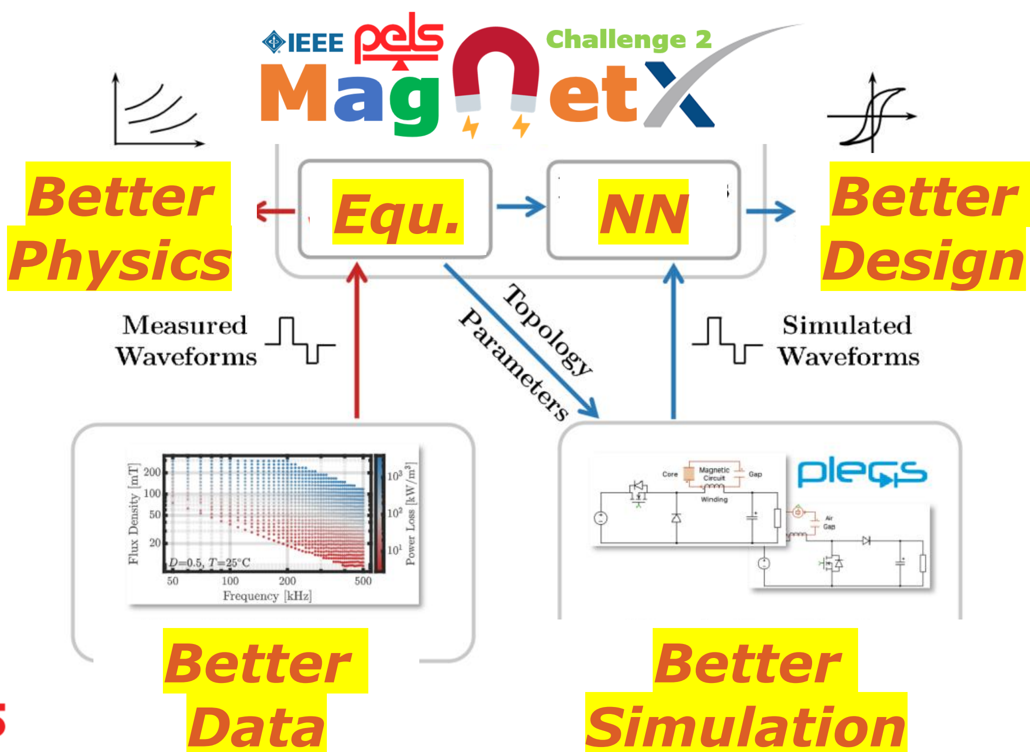
An example PFC converter

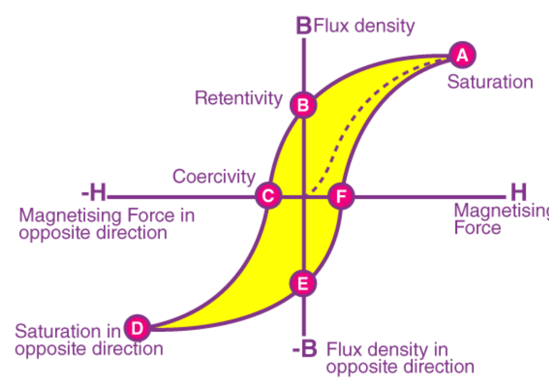


Make every AC-DC adapters 30% smaller?

Outcomes of MagNet Challenge 2

- Better understandings about power magnetics.
- Better tools for power magnetics design.
- Better ways of sharing information (digital/interactive datasheet).
- Cultivate an open-source community.
- Better impact for practical design.

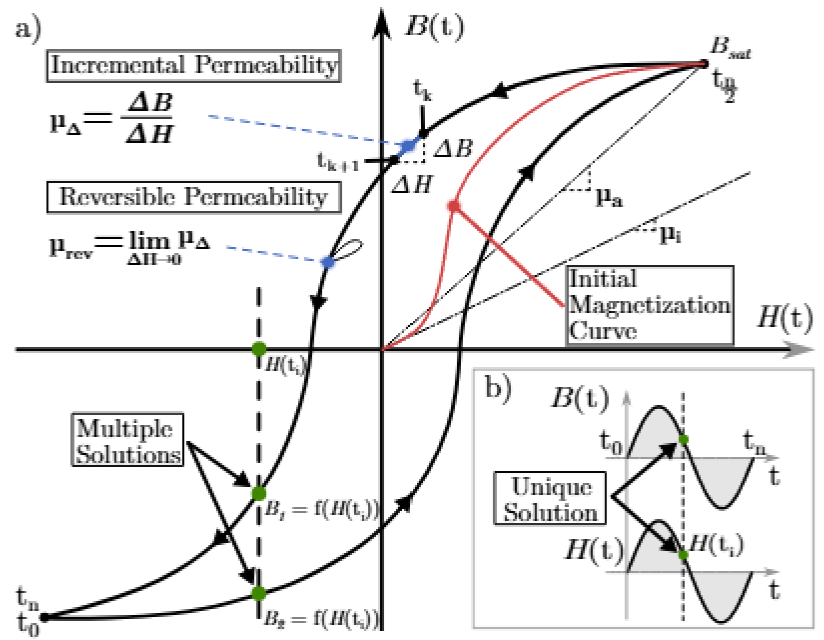


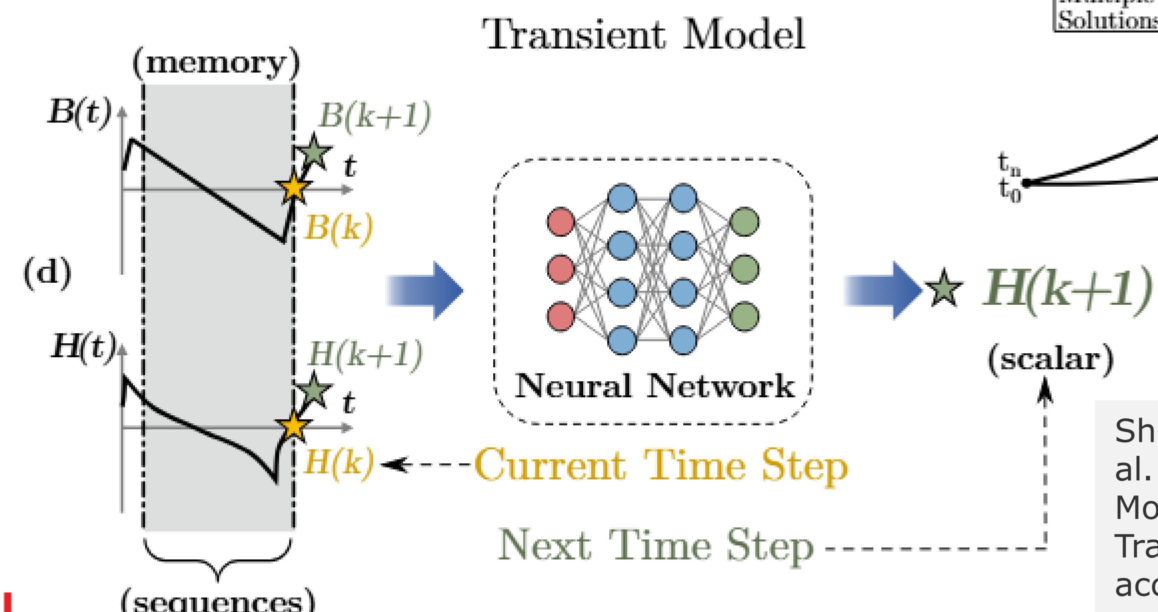


- Hysteresis loop exists for almost all energy materials
- Magnetics, capacitors, piezoelectric, batteries, etc.

A Compact Model for Next B-H Steps

Input: B(t) in the past 100 steps
H(t) in the past 100 steps
an arbitrary B(t+1)
Output: the corresponding H(t+1)





Shukai Wang, Hyukjae Kwon, Haoran Li, et al. MagNetX: Foundation Neural Network Models for Simulating Power Magnetics in Transient. *TechRxiv.* December 11, 2024. accepted to APEC 2025.

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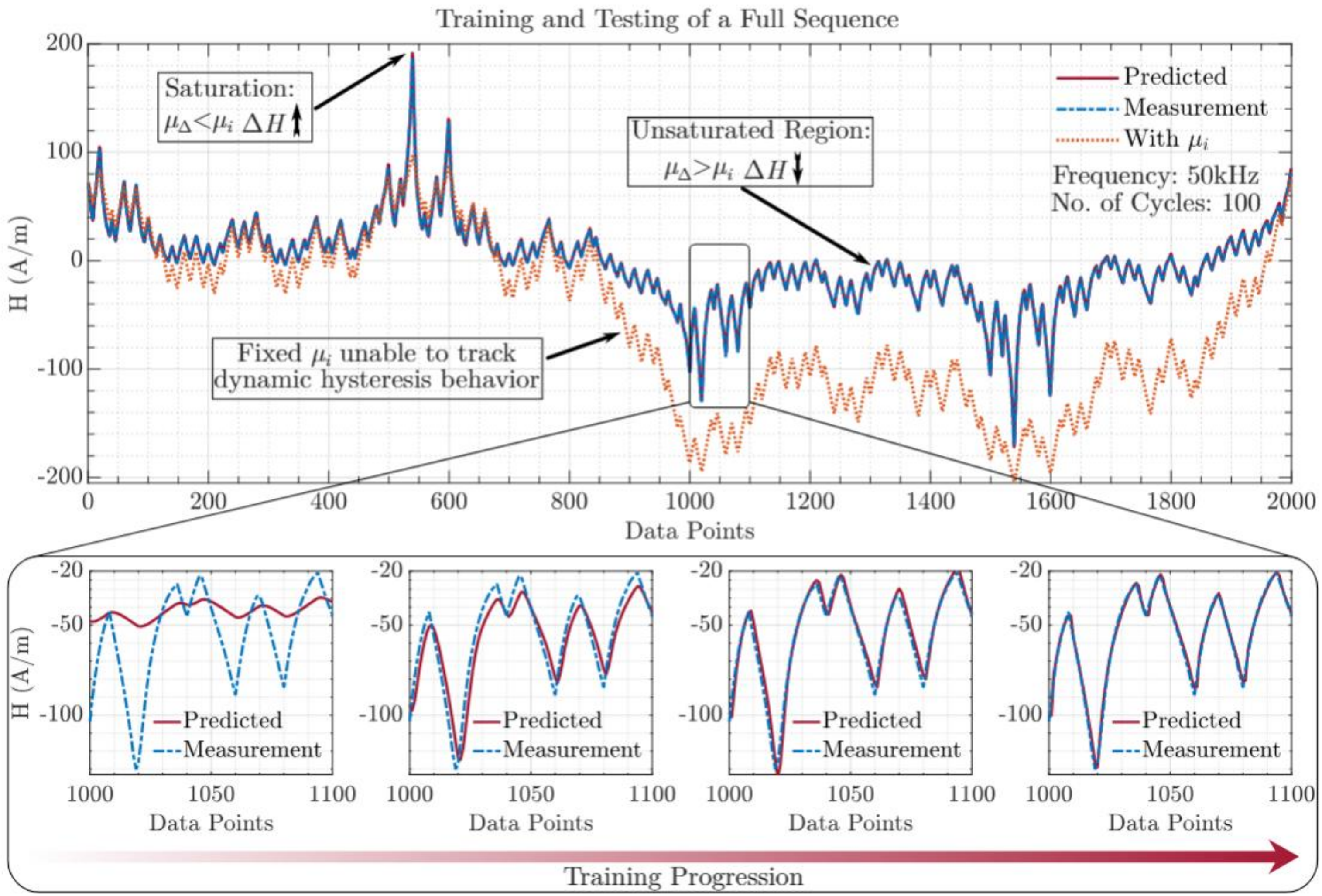
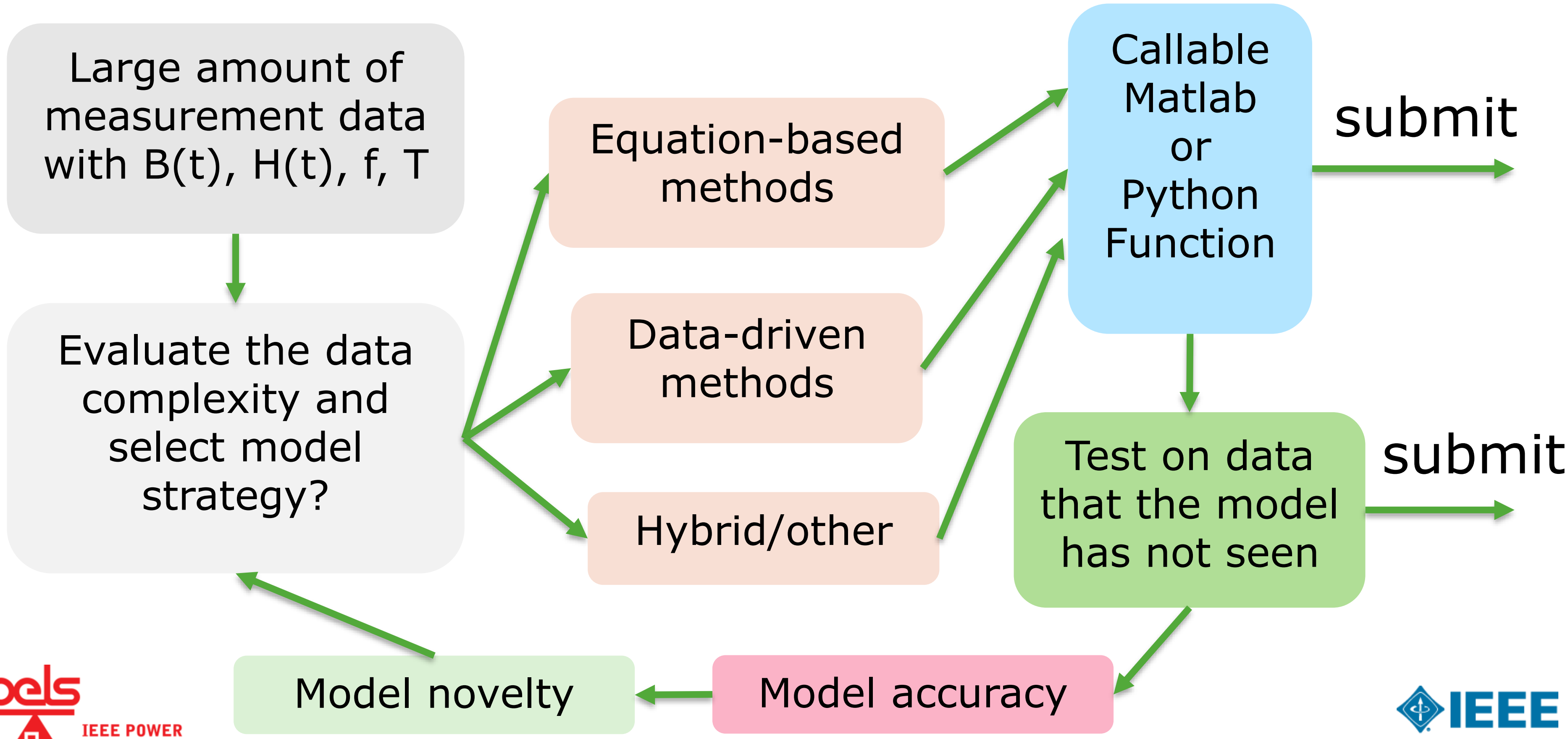
A Large Models for Long Excitation Cycles



Information Flow of MagNet Challenge

Next step $H_{T+1} = function\,(B(t), H(t), B_{T+1}, temperature)$

Long cycle $H(t) = function\,(B(t), temperature)$



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Timeline of MagNet Challenge 2

Feb 1st, 2025	Initial Call for Participation Announcement
March 18th, 2025	**APEC Official Announcement**
April 1st, 2025	Online Q&A Session
May 1st, 2025	1-Page Letter of Intent Due with Signature [Attached]
June 1st, 2025	2-Page Proposal Due for Eligibility Check [TPEL Format]
July 1st, 2025	Notification of Acceptance [Eligibility Check]
Nov 1st, 2025	Preliminary Submission Due, Finalists Selected
Dec 24th, 2025	Final Submission Due
March 1st, 2026	Winner Announcement and Presentation

April 1st - Large amount of data for 10 materials released

May 1st – 1-Page letter of intent due

June 1st – 2-Page proposal due

July 1st – All participating teams confirmed

Nov 1st – Callable models for 10 materials due

Nov 1st – Release small training data for 3 new materials

Dec 24th – Callable models and predicted core loss (Pv) for 10+3 materials under a variety of {B(t), f, T} conditions, and a 5-page TPEL format report due

March 1st , 2024 – Winner Announcement

MagNet Methodology

- Develop methods on **old** materials
- Test methods on **new** materials
- Train models with **small** datasets
- Test models with **large** datasets

Student Team Eligibility

- **Eligibility:** To confirm eligibility, potential participating schools must submit a Letter of INTENT (attached) by **May 1st, 2025**, to pelsmagnet@gmail.com, for better coordination.
- For each team, the minimum student number is **three (3)** and the maximum student number is **five (5)** to qualify for the competition. Each team should consist of between **one (1) to two (2)** undergraduate students (B.S. or equivalent), between **two (2) to three (3)** graduate students (M.S./Ph.D. or equivalent), and at least **one (1)** faculty advisor and optionally **one (1)** industry mentor. Interdisciplinary and diversified teams are highly encouraged.
- Note: We will try to host as many teams as possible. We can perhaps host **2-3 teams per university** depending on the final total participating team numbers and the quality of the proposals.
- Members of the judging committee will be replaced if there is a conflict from the same university. Student teams will NOT be judged by experts with conflicts of interest.
- We will invite **20-30 prominent researchers** from academia and industry as scientific advisors to student teams.

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Evaluation Criteria

- **Winning solution: a simple, robust, and trustworthy method to**
  - **(1) accurately predict power magnetic behaviors**
  - **(2) efficiently use the training data**
  - **(3) provide useful design insights**
  - **(4) advance understanding about power magnetics**
  - **(5) other novel contributions to the field**

- **Model performance:** 95^{th} percentile error on rms error in B-H sequence.
- **Model size:** number of material-specific parameters that need to be kept in the model. Jointly evaluated by submitted package size and code review.
- **Model novelty:** new insights and new methods in physical understanding, data processing, model development, and anything else related to power magnetics.
- **Model generality:** extending the developed model to different materials.

Final Winners selected by the Academic Advisory Committee:

- Charles Sullivan, Dartmouth, USA
- David Perreault, MIT, USA
- Johann Kolar, ETH Zurich, Switzerland
- SY Ron Hui, NTU, Singapore
- Dragan Maksimovic, UC Boulder, USA

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Award Structure

Tesla Award for Model Performance 1st Place \$10,000	Google Award for Model Novelty 1st Place \$10,000	Princeton CSML Award for Outstanding Software Engineering \$5,000
PELS Award for Model Performance 2nd Place \$5,000	PELS Award for Model Novelty 2nd Place \$5,000	PELS Honorable Mentions \$1,000 x multiple

- Performance
- Model size

- Novelty
- Model generality

- Software implementation
- Other contributions

Intellectual Property

- MagNet Challenge 2 has no restrictions on intellectual property.
- We encourage open-source culture and open-source licenses.
- Presenting the models to MagNet team is considered as public disclosure.
- Student teams should take actions before disclosure if IP protection is needed.

Extended Reading

- **J-A Model –** D. Jiles and D. Atherton, "Theory of ferromagnetic hysteresis," Journal of Magnetism and Magnetic Materials, vol. 61, no. 1, pp. 48–60, 1986.
- **Preisach Model –** F. Preisach, "Uber die magnetische Nachwirkung," Zeitschrift fur Physik,vol. 94, no. 5-6, pp. 277–302, May 1935.
- **LLG Model –** H. H. Cui, S. Dulal, S. B. Sohid, G. Gu, and L. M. Tolbert, "Unveilingthe microworld inside magnetic materials via circuit models," IEEEPower Electronics Magazine, vol. 10, no. 3, pp. 14–22, 2023.
- **iGSE-PFC –** M. J. Jacoboski, A. de Bastiani Lange and M. L. Heldwein, "Closed-Form Solution for Core Loss Calculation in Single-Phase Bridgeless PFC Rectifiers Based on the iGSE Method," in IEEE Transactions on Power Electronics, vol. 33, no. 6, pp. 4599-4604, June 2018.
- **Why MagNet –** D. Serrano et al., "Why MagNet: Quantifying the Complexity of Modeling Power Magnetic Material Characteristics," in IEEE Transactions on Power Electronics, vol. 38, no. 11, pp. 14292-14316, Nov. 2023.
- **How MagNet –** H. Li et al., "How MagNet: Machine Learning Framework for Modeling Power Magnetic Material Characteristics," in IEEE Transactions on Power Electronics, vol. 38, no. 12, pp. 15829-15853, Dec. 2023.
- **MagNet-AI –** H. Li, D. Serrano, S. Wang and M. Chen, "MagNet-AI: Neural Network as Datasheet for Magnetics Modeling and Material Recommendation," in IEEE Transactions on Power Electronics, vol. 38, no. 12, pp. 15854-15869, Dec. 2023.
- **MagNet Challenge –** M. Chen et al., "MagNet Challenge for Data-Driven Power Magnetics Modeling," in IEEE Open Journal of Power Electronics, accepted.