A Historic Gap in US R&D Sustained Investments: Passives and Magnetics Research

Wide Bandgap Devices are Creating New Challenges and Opportunities for Passives, Including Magnetics … Breakthrough Passives and Magnetics Research Requires Sustained and Focused R&D Efforts.

Current State of the Power Magnetics Community:
1) US R&D in Soft Magnets and Components Below “Critical Mass”
2) Challenges Exist for Identification of Qualified Technical Talent at All Career Levels
3) Lack of a Robust, Diversified Supply Chain for Advanced Soft Magnetic Alloys and Manufacturing

Federal Programs Have Begun to Realize the Importance of this Area and the Situation is Improving.

There is a Need for Long-Term R&D and Educational Programs to Ensure Sustainability.
**Grid-Scale Magnetics: Opportunities & Needs for Near-Term Technologies**

**Distribution Transformers**

Opportunity = Quad-Level Energy Loss Reduction

Need = Higher Efficiency Core Materials at 60Hz

**Options**

→ Promote Deployment of Commercial Amorphous Alloys Having 30% Core Losses of Electrical Steel
  (Policy, Regulation, Diversification of Supply Chain)

→ Develop New **Scalable** Alloy Technologies with Higher Saturation Inductions & Lower Core Losses
  (R&D in Materials and Manufacturing)

~2% of all electricity generated is lost due to distribution transformer efficiency

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**Table: Distribution Transformer Efficiency**

<table>
<thead>
<tr>
<th>Region / Country</th>
<th>Electricity Consumption (TWh) 1</th>
<th>Distribution Transformer Core Losses (TWh) 2</th>
<th>Potential Annual Savings with AMOF's Year (TWh) 3</th>
<th>Potential Annual Savings with AMOF's (Millions, USA 4)</th>
<th>Annual CO2 Reduction in Millions of Tons 5</th>
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</thead>
<tbody>
<tr>
<td>USA</td>
<td>3901</td>
<td>33.2</td>
<td>22.2</td>
<td>1670</td>
<td>13.6</td>
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<tr>
<td>EU27</td>
<td>3034</td>
<td>25.8</td>
<td>19.0</td>
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<td>China</td>
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<td>1545</td>
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<td>7.2</td>
<td>5.8</td>
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<td>India</td>
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<tr>
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<td>3.0</td>
<td>225</td>
<td>0.2</td>
</tr>
</tbody>
</table>

https://metglas.com/distribution-transformer-electrical-steel/
Grid-Scale Magnetics: Opportunities & Needs for Near-Term Technologies

MV Power Electronics
(e.g. SSTs, DER MV Grid-Tie Inverters, Microgrid Applications)
Opportunity = Highly Efficient & Flexible MV Power Electronics
Need = Advanced Core Materials and Transformer Design Strategies @ 1-100kHz, 1-13.8kV, 10kW+

Options
→ Develop New Scalable Core Materials with a Combination of High Bs, Low Loss, High Resistivity
  (R&D in Materials and Manufacturing)
→ Develop Novel Transformer Architectures and Designs with Low Losses, Reduced Parasitics, Engineered Leakage
  (R&D in Transformer Modeling and Manufacturing)

https://www.nap.edu/read/21712/chapter/8
Grid-Scale Magnetics: Opportunities & Needs for Long-Term Technologies

MV, MW-Scale Drives for Large Scale Electrical Machinery
Opportunity = Implementation of Variable Speed Drives
Need = Filter Inductors with High Linearity and Low Losses

Options

→ Develop New **Scalable** Core Materials with High Saturation Inductions, Low Losses, and **Tunable Permeability**
  (R&D in Materials and Manufacturing)

→ Improved Thermal Management and Reliability
  (R&D in Thermal Management Technology)

A. Hefner, Workshop on Enabling Technology for High MW Machines,
Grid-Scale Magnetics: Opportunities & Needs for Long-Term Technologies

MV to HV and High Power Magnetics
(e.g. Large Power Transformer, Solid State Substation)
Opportunity = Isolation, Modularity, Functionality, Resilience
Need = MV – HV Solid-State Transformer Technology

Options
→ Develop Novel Transformer Architectures and Designs with Low Losses, Reduced Parasitics, Engineered Leakage
  (R&D in Transformer Modeling and Manufacturing)
→ Develop Transformer Architectures for Ease of Isolation
  (R&D in Transformer Modeling and Manufacturing)


Crosscutting Needs: Magnetics Component Characterization

Application Relevant Magnetic Component Characterization:

1) Losses Under Converter Specific Excitation
2) Electrical Characterization \( (R_{\text{winding}}, I_{\text{leakage}}, C_{\text{parasitic}}) \)
3) Stray Fields and Electromagnetic Interference
4) Thermal Characterization


Crosscutting Needs: Magnetics Component Modeling Techniques

Electromagnetic, Circuit, and Thermal Modeling:

1) Finite Element Modeling Methods
2) Magnetic Equivalent Circuits
3) Electrical Equivalent Circuits
4) Thermal Equivalent Circuits
Crosscutting Needs: Magnetic Component Design Tools

B-H Loop Parameterization
"Anhysteretic Modeling"

Core Loss Parameterization and Modeling

\[ P_w = P_{f} + P_{c} = k_{h} \cdot f \cdot B\beta_{h} + k_{e} \cdot (f \cdot B)^{\beta_{e}} \]

Magnetic Component Design Tools:
1) B-H Loop Parameterization Models
2) Core and Winding Loss Models
3) Capacitance and Leakage Inductance Models
4) Analytical Optimization Algorithms


Crosscutting Needs:
Core Materials and Manufacturing Methods

Materials Synthesis and Fabrication

Core Materials and Manufacturing Methods:
1) New Alloys and Core Materials (High Bs, Low Loss)
2) Advanced Scalable Manufacturing Processes
3) “Permeability Engineering” Methods

Advanced Processing Techniques

Locally Engineered Permeabilities

Materials Synthesis and Fabrication

Advanced Processing Techniques

Locally Engineered Permeabilities

Amorphous and Nanocomposite Materials

AM Leary, PR Ohodnicki, ME McHenry, JOM 64 (7), 772-781 (2012).
Recent Innovative Breakthroughs and Success

Development of New Core Testing Circuits

Real Time, Distributed Thermal Monitoring

Ferrite Shielding Techniques for Reducing Transformer Losses

Provisional Patent: 98192/1063283, 62/583,843, November 10, 2017, United States

Provisional Patent: 221404-8470, 62/582,107, November 6, 2017, United States

Advanced Permeability Engineered Cores

Graded Permeability

Ferrite

Nanocomposite Cores

Fabricated Core

Constant

Graded Permeability

Advanced Manufacturing Office


Recent Innovative Breakthroughs and Success

Co-Based Nanocomposite
Strain Annealed Inductors for 1MW Motor Drive

Strain Annealed
Ribbon up to 2” Wide

Mass = 10kg, L=400μH
V\text{primary} = 3\text{kV}, I\text{primary} = 450\text{A Peak}

Advanced Transformer Designs with Nanocomposite Core Materials for Solar and Energy Storage Grid Integration Power Electronics

Multi-Port DC-DC Converter Solar PV + ES


Key Take-Away Messages

• Needs and Opportunities Exist for Advances in Magnetics Components for Emerging Grid Applications

• Emerging Trends Demand Advances in a Number of Magnetic Component Technologies
  • Higher Efficiency Core Materials for Distribution Transformers
  • New Core Materials, Transformer Designs and Manufacturing for Medium Voltage Power Electronics
  • Filter Inductors with Low Loss and High Linearity for Medium Voltage Drives
  • New Transformer Architectures for Optimized Parasitics, Leakage, and Isolation for HV+ Applications
  • Thermal Management Strategies and Methods

• Crosscutting Needs Exist Spanning Characterization, Modeling, Design, Materials, Scalable Manufacturing

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