P/O/E/T/S

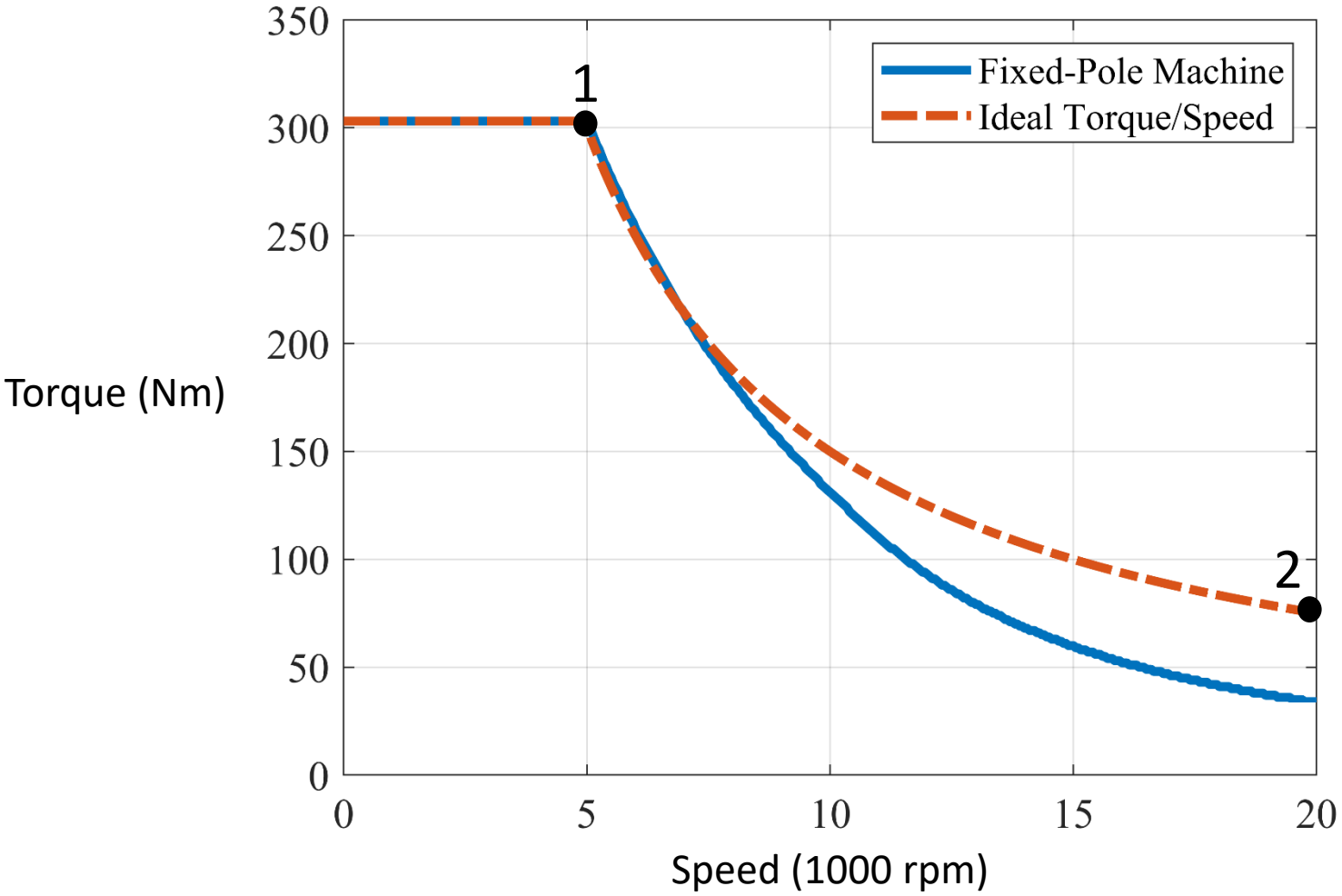
CENTER FOR POWER OPTIMIZATION OF ELECTRO-THERMAL SYSTEMS

Variable-Pole Induction Machines and Drives for Electric Vehicles

Elie Libbos (University of Illinois at Urbana-Champaign)

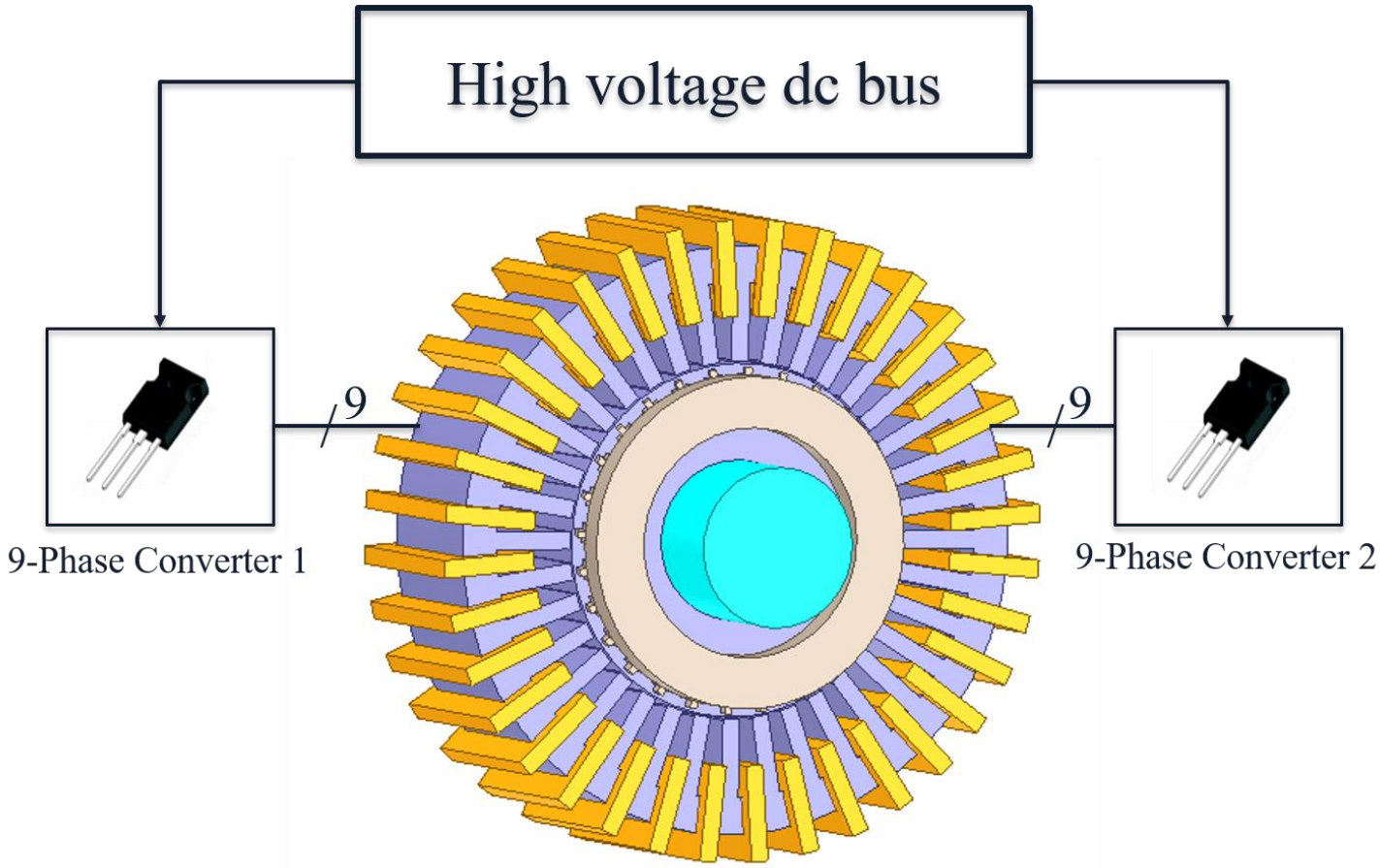
Problem

Fixed-pole induction machine suffers at high-speed



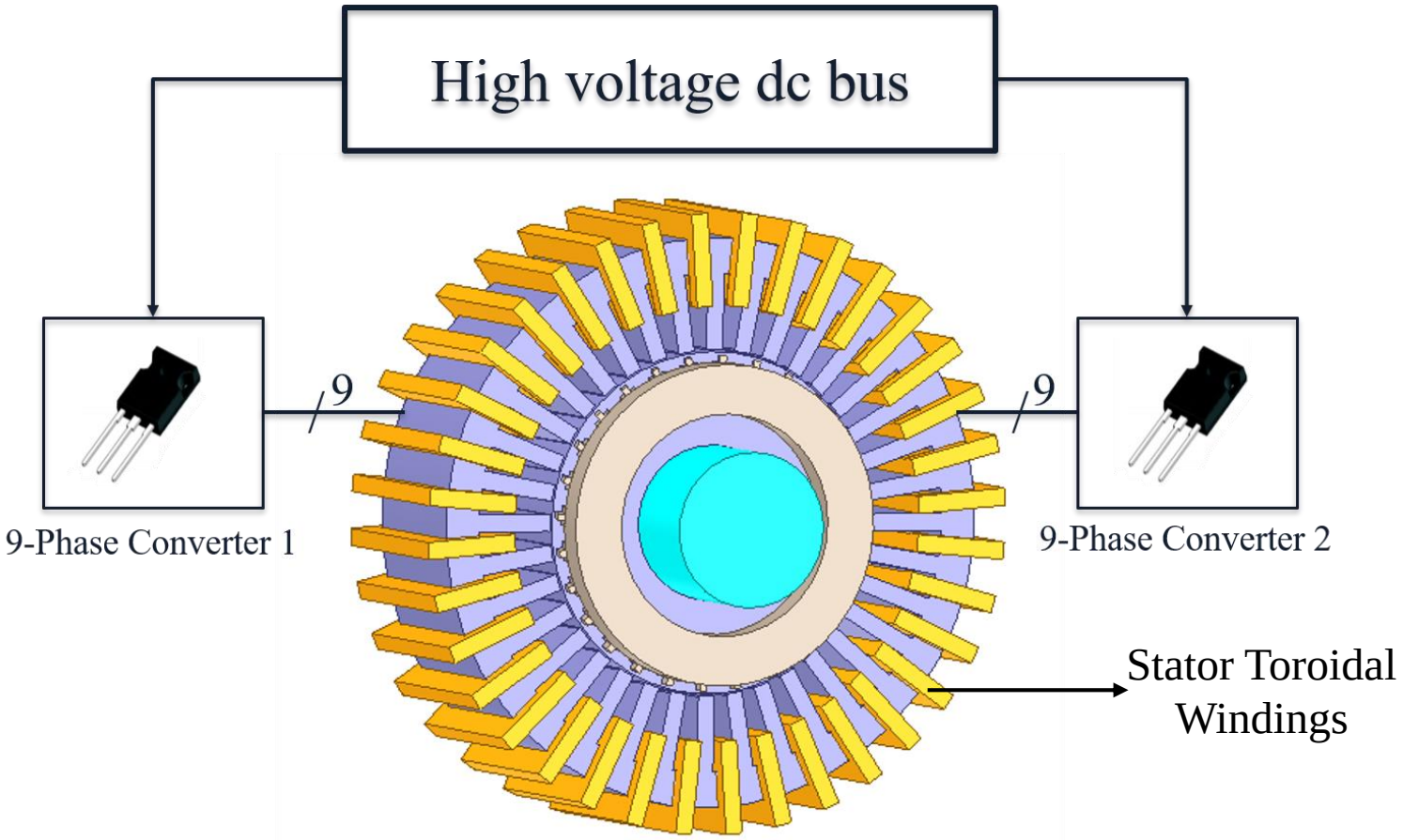
General Concept

Co-design and control of variable-pole induction machine and drive for an EV.



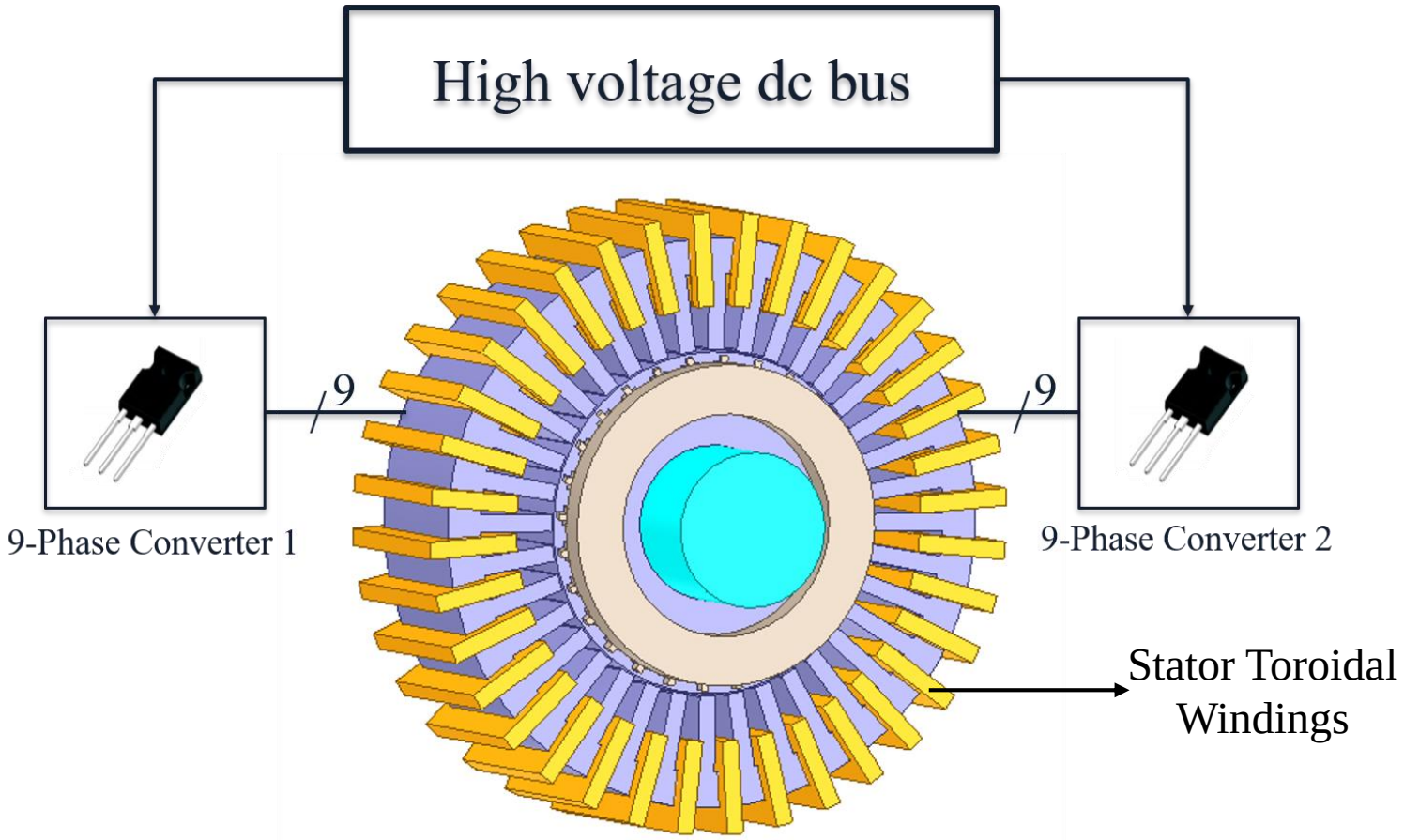
General Concept

Stator winding and power electronics co-design is required to vary the induction machine pole count.

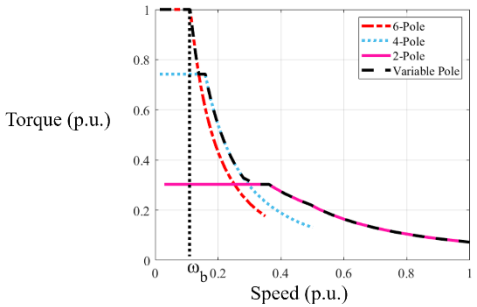


General Concept

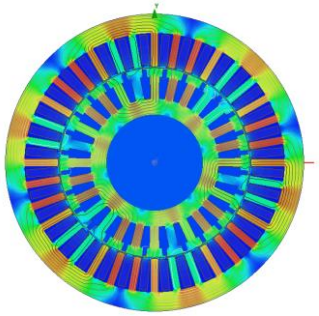
Vision: electromagnetic and thermal co-design of variable-pole induction machine and power electronics.



Outline



Why variable-pole IM?

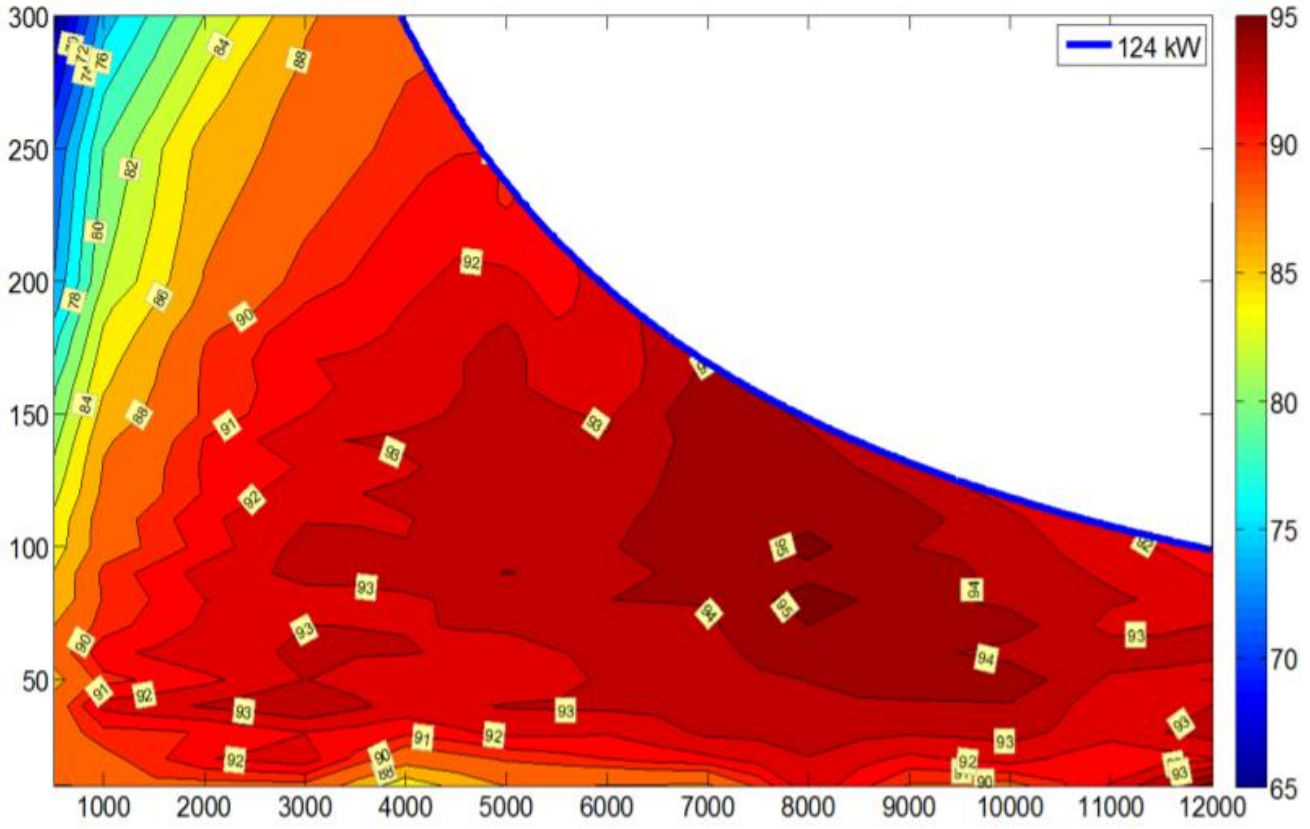


Loss minimization using variable-pole IM

Can we reduce losses in a real machine?

EV Drivetrain Requirements

Torque (Nm)

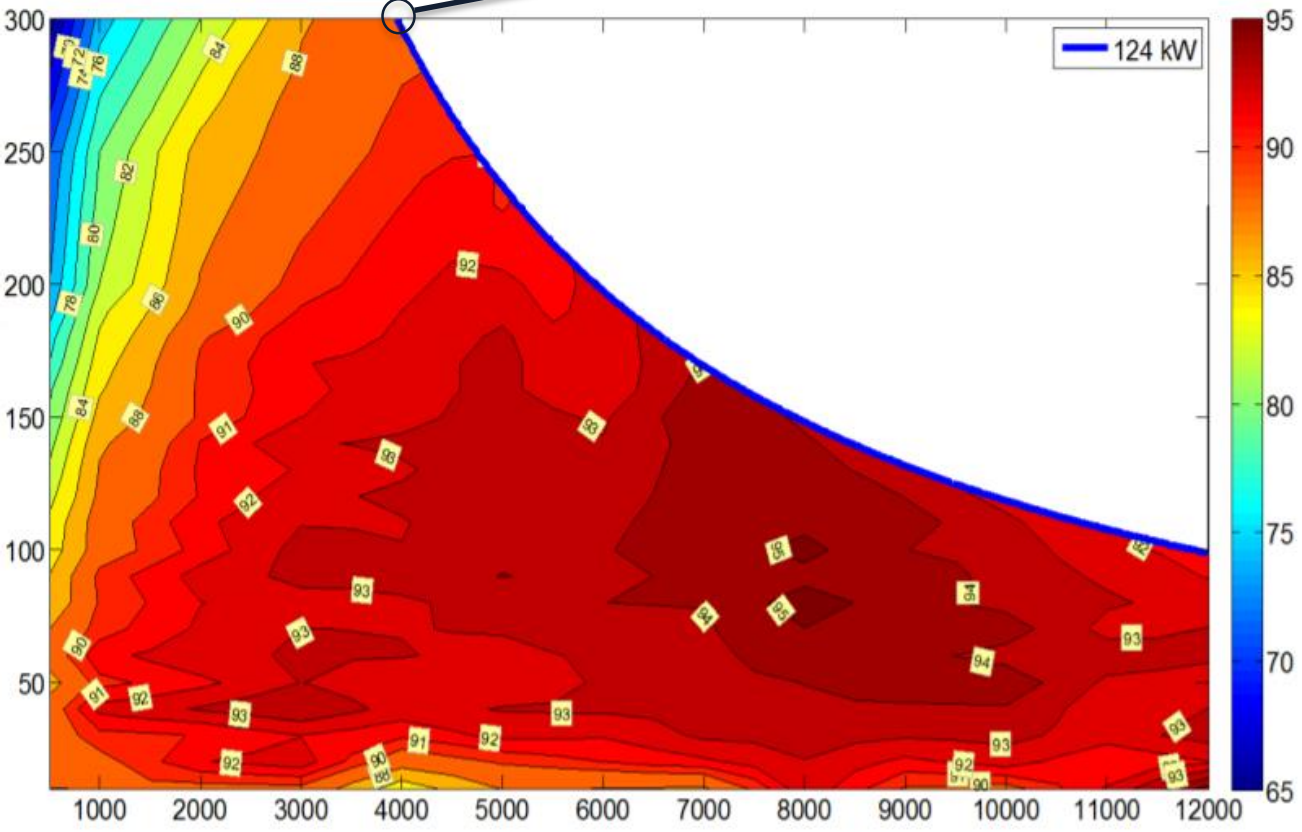


Speed (rpm)

"US DRIVE Electrical and Electronics Technical Team Roadmap," 2017. [Online]. Available: https://www.energy.gov/sites/prod/files/2017/11/f39/EETT Roadmap 10-27-17.pdf. [Accessed: 30-April-2020].

EV Drivetrain Requirements

High torque until base speed



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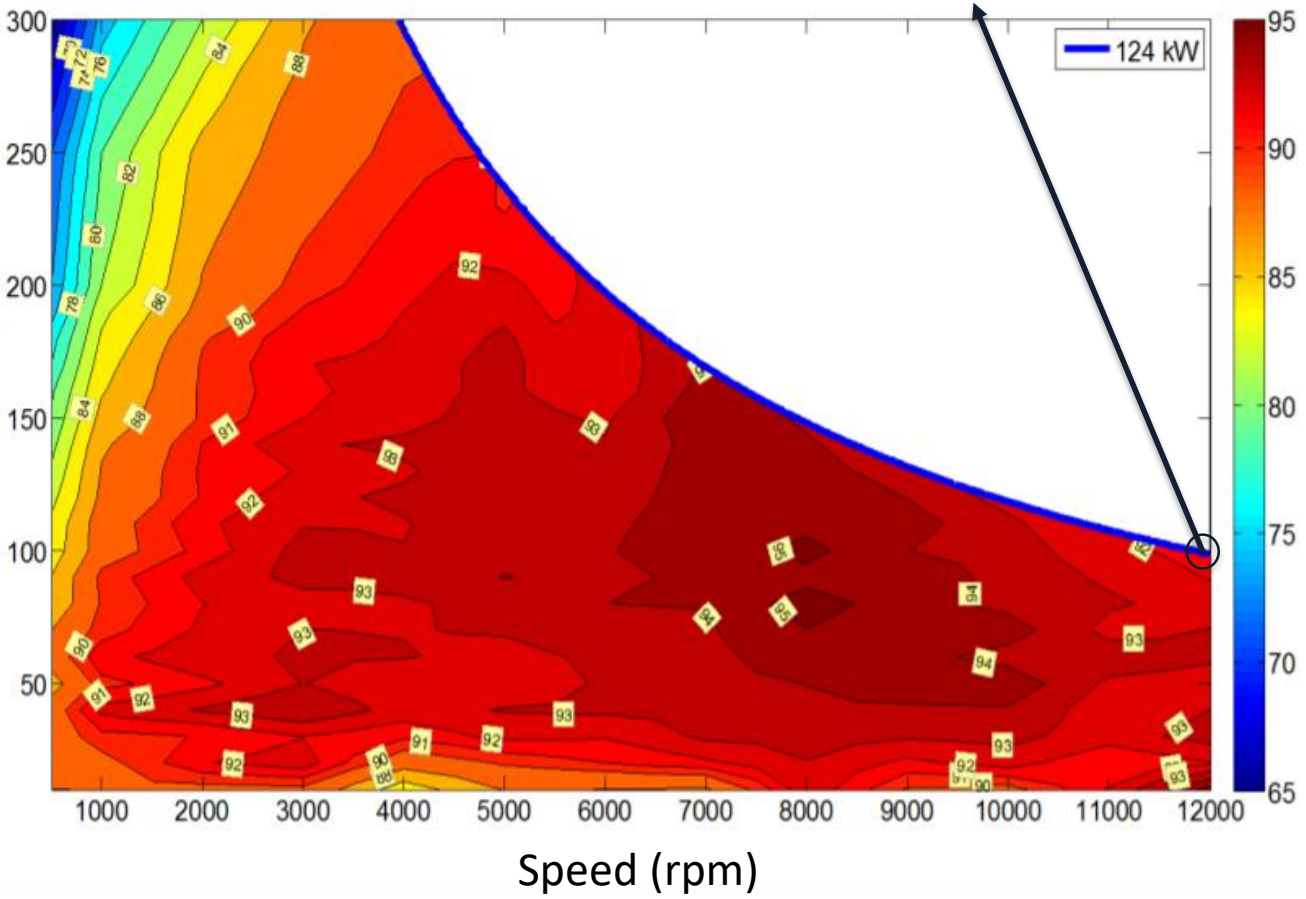
EV Drivetrain Requirements

High speed operation



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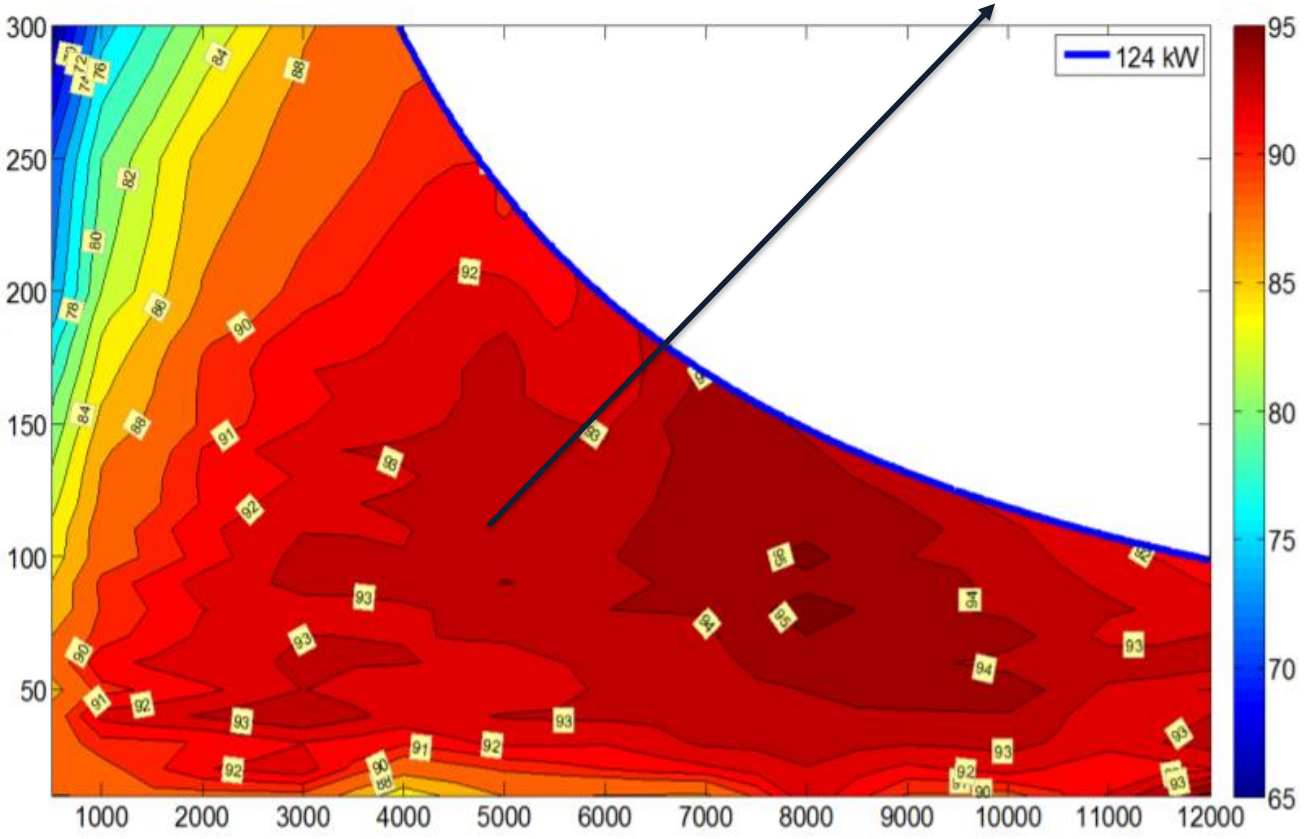
EV Drivetrain Requirements

Wide high efficiency region



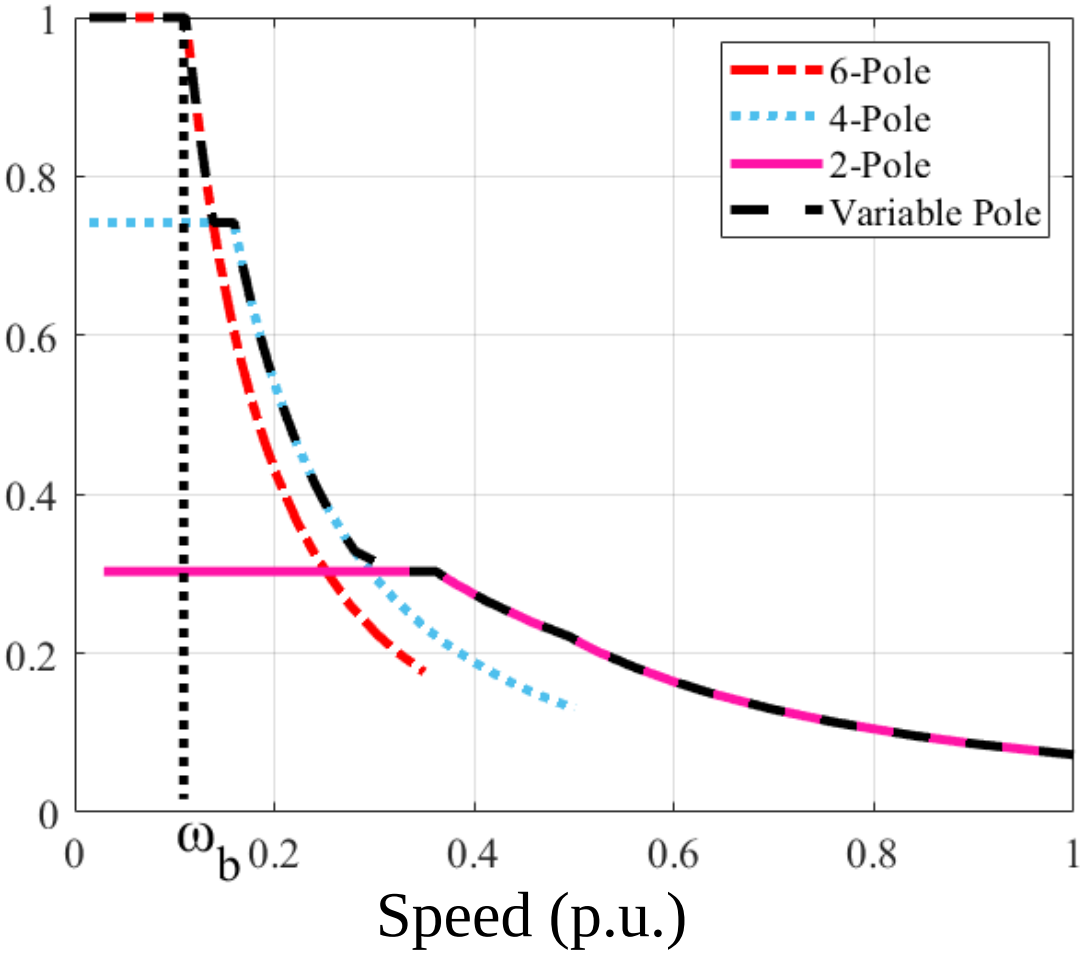
Torque (Nm)

Speed (rpm)

"US DRIVE Electrical and Electronics Technical Team Roadmap," 2017. [Online]. Available: https://www.energy.gov/sites/prod/files/2017/11/f39/EETT Roadmap 10-27-17.pdf. [Accessed: 30-April-2020].

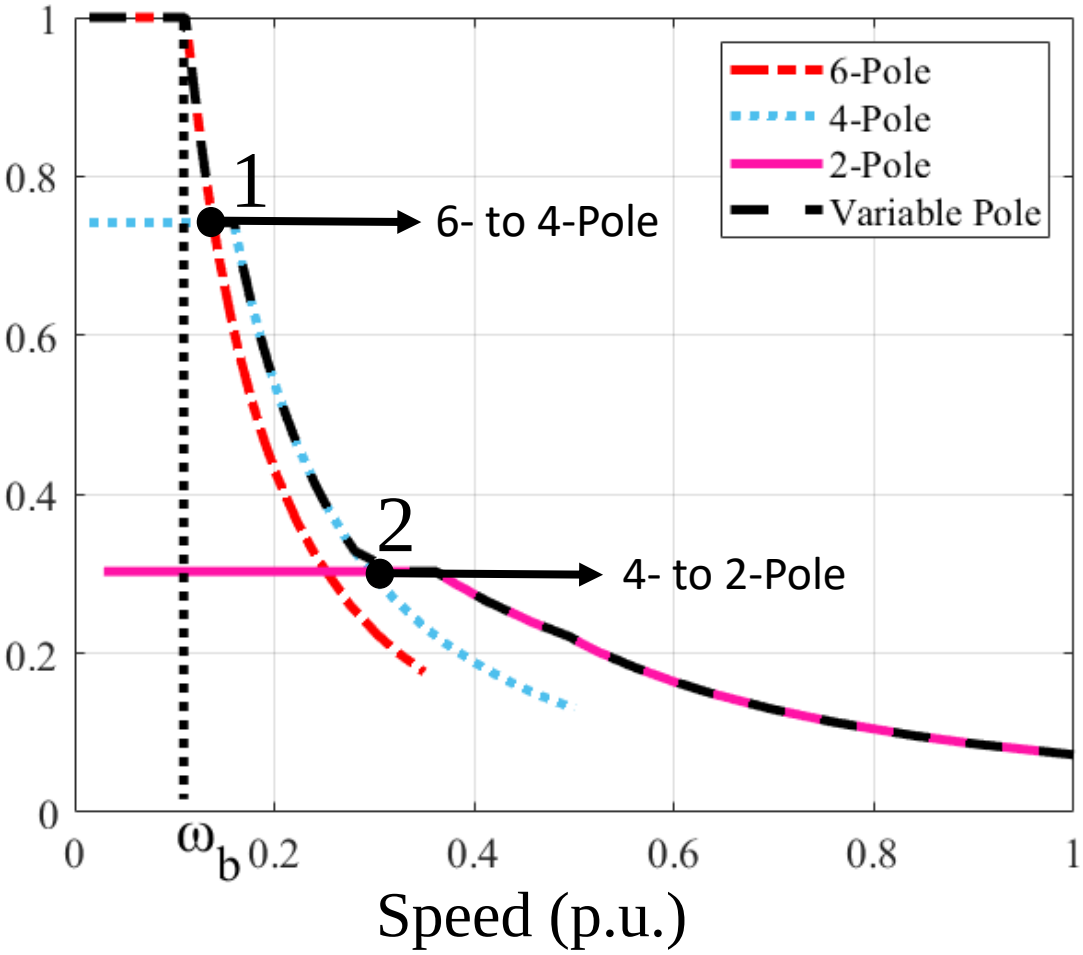
Fixed-Pole IM Problem

Torque capability of 6-pole drops significantly beyond base speed



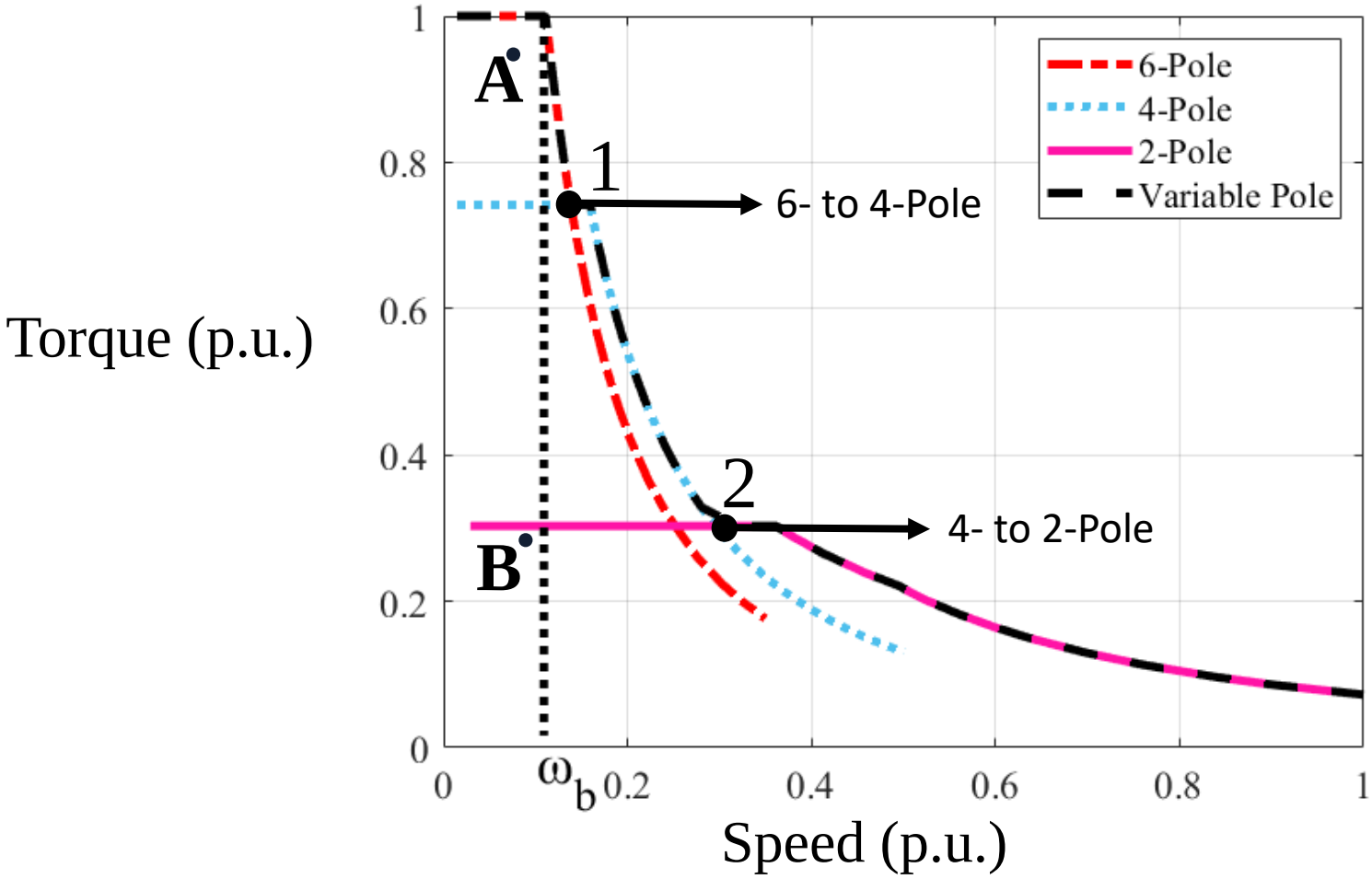
Variable-pole induction machine

Lower pole counts improve high speed torque capability.

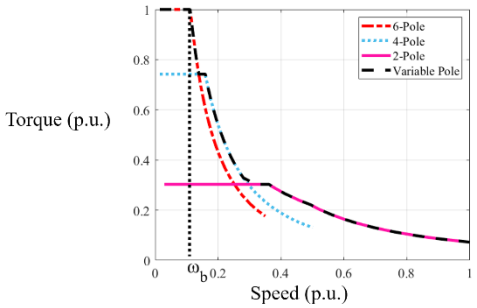


Variable-pole induction machine

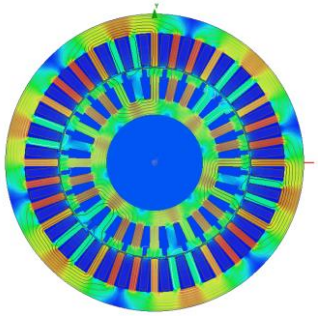
How do we select the pole count at point B?



Outline



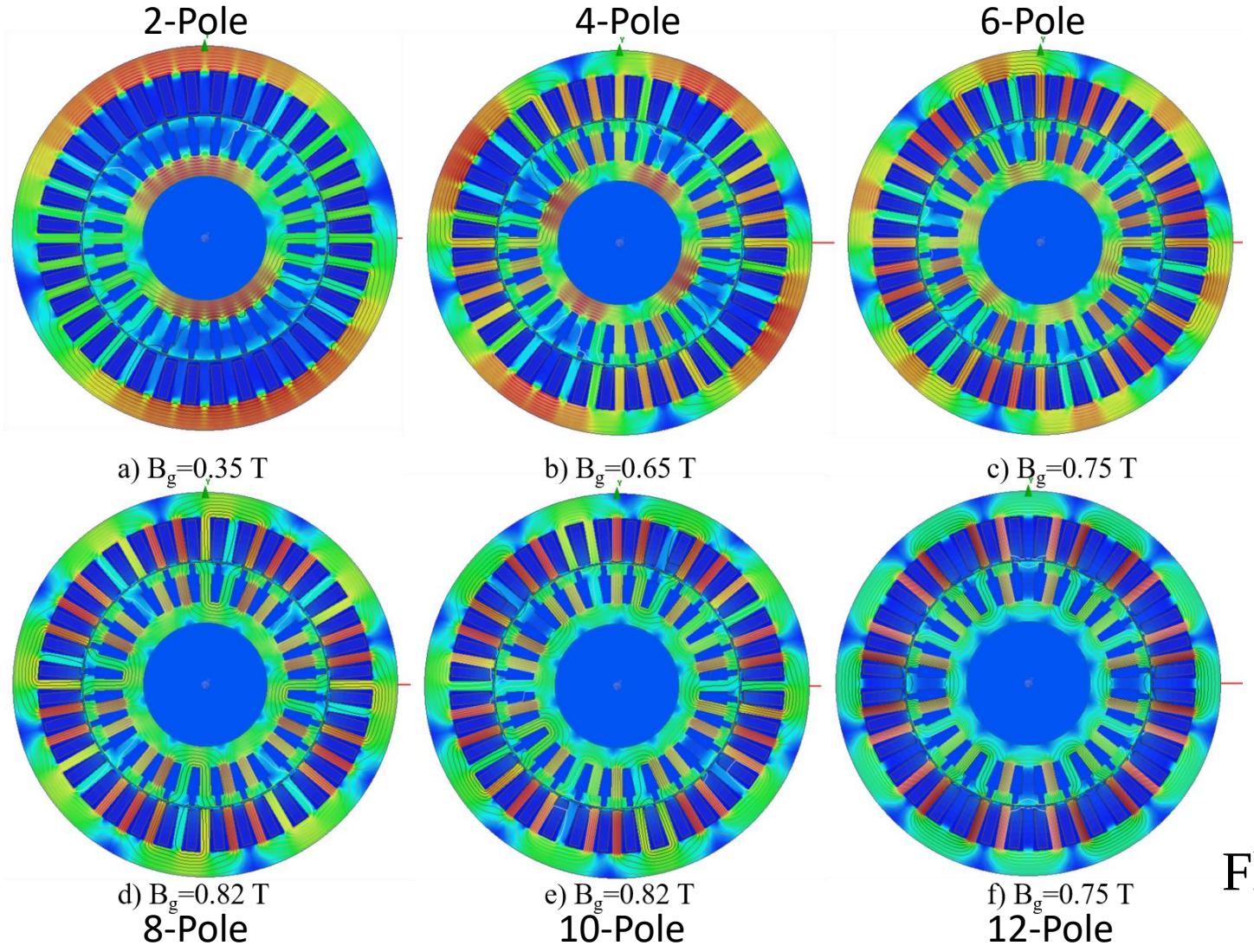
Why variable-pole IM?



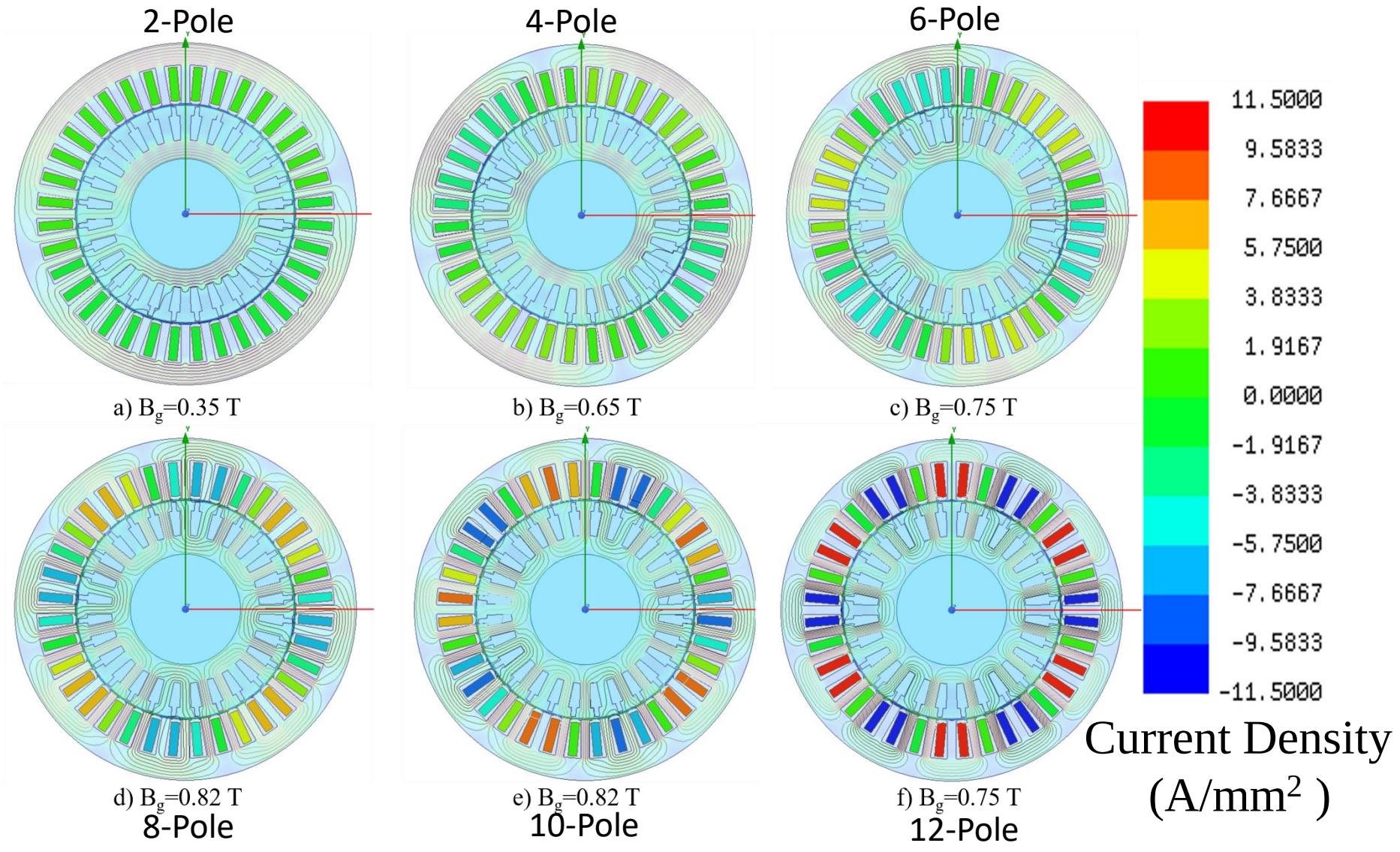
Loss minimization using variable-pole IM

Can we reduce losses in a real machine?

Electromagnetics of variable-pole

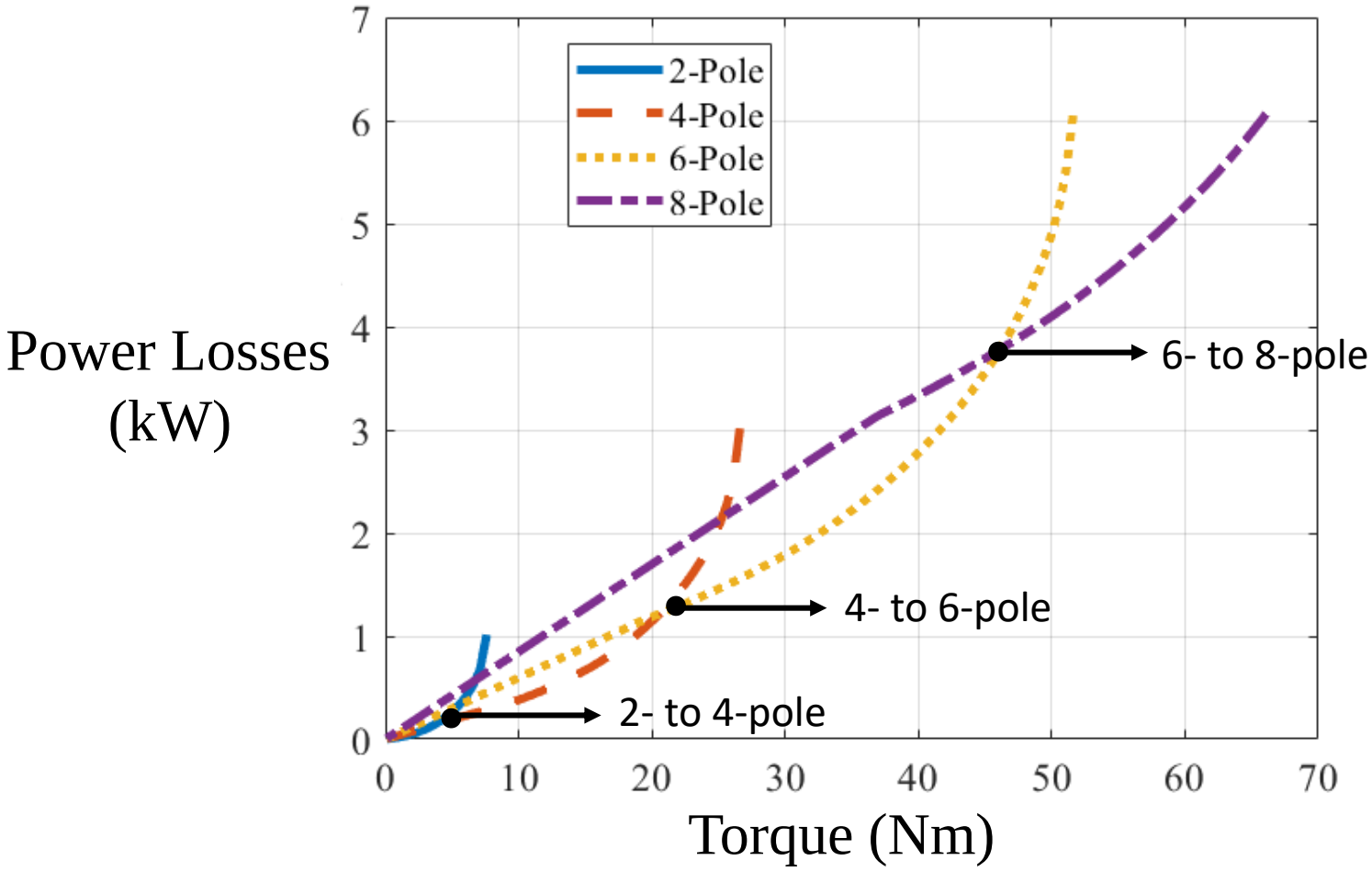


No-load current density



Loss minimization using pole count

Lower pole counts improve partial loading efficiency



E. Libbos, B. Ku, S. Agrawal, S. Tungare, A. Banerjee, and P. T. Krein, "Loss minimization and maximum torque per ampere operation for variable-pole induction machines," IEEE Transactions on Transportation Electrification, (Accepted).

Loss minimization using pole count

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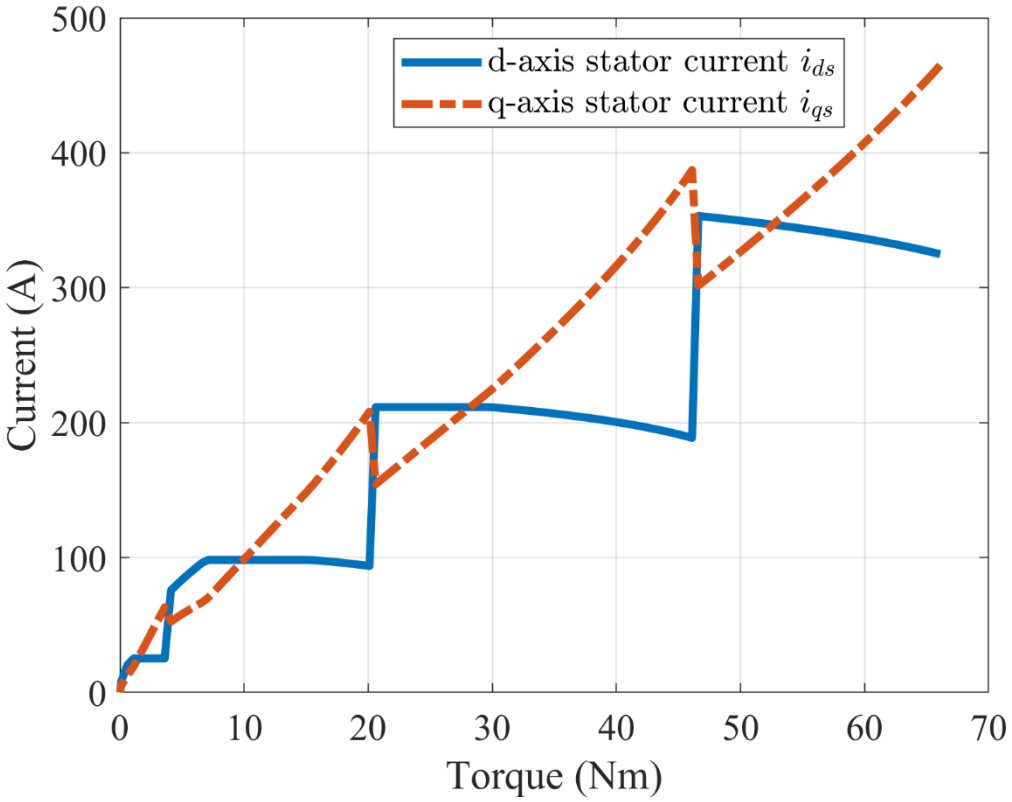

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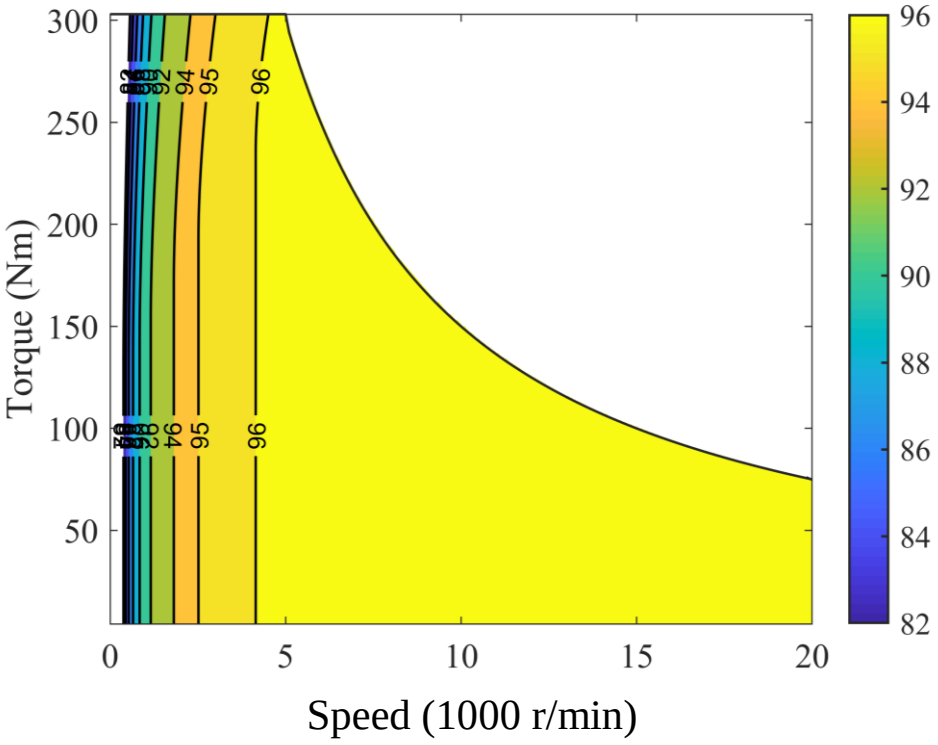
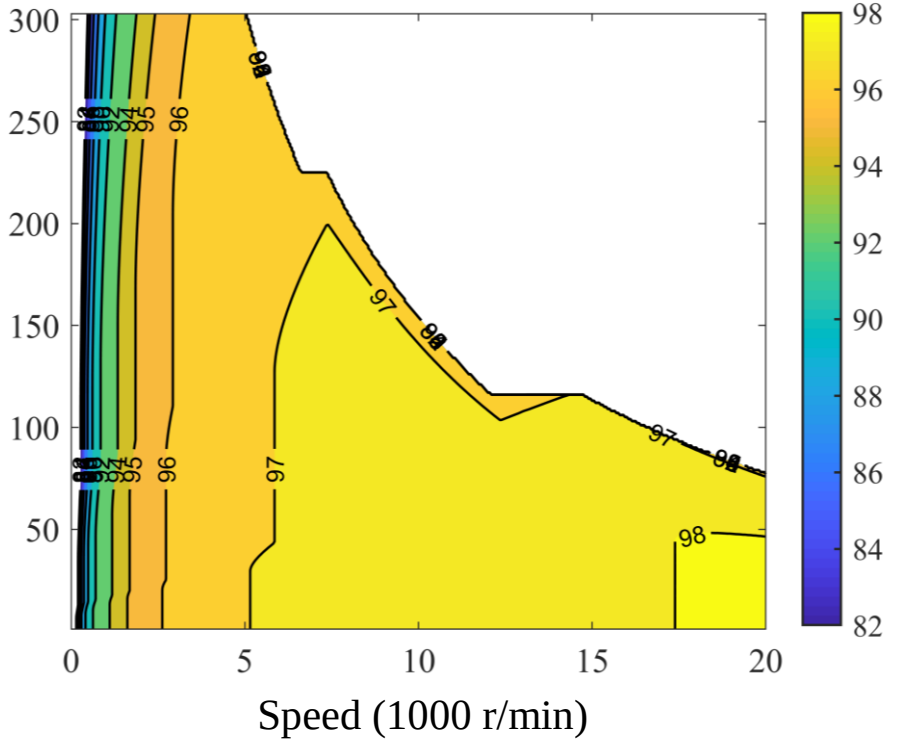
Variable-pole Induction Machine

Variable-pole machine meets the ideal torque speed requirement.

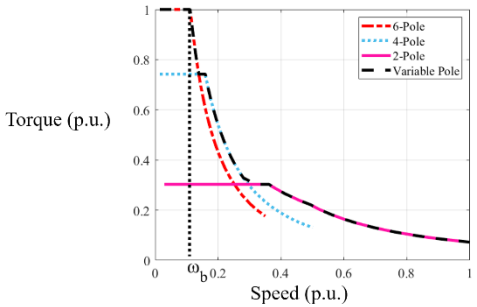
Fixed-Pole



Variable-Pole



Outline



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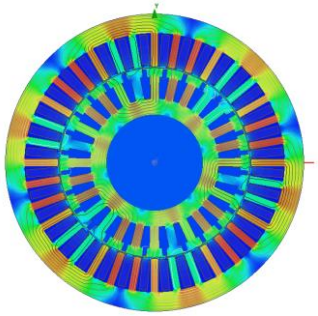
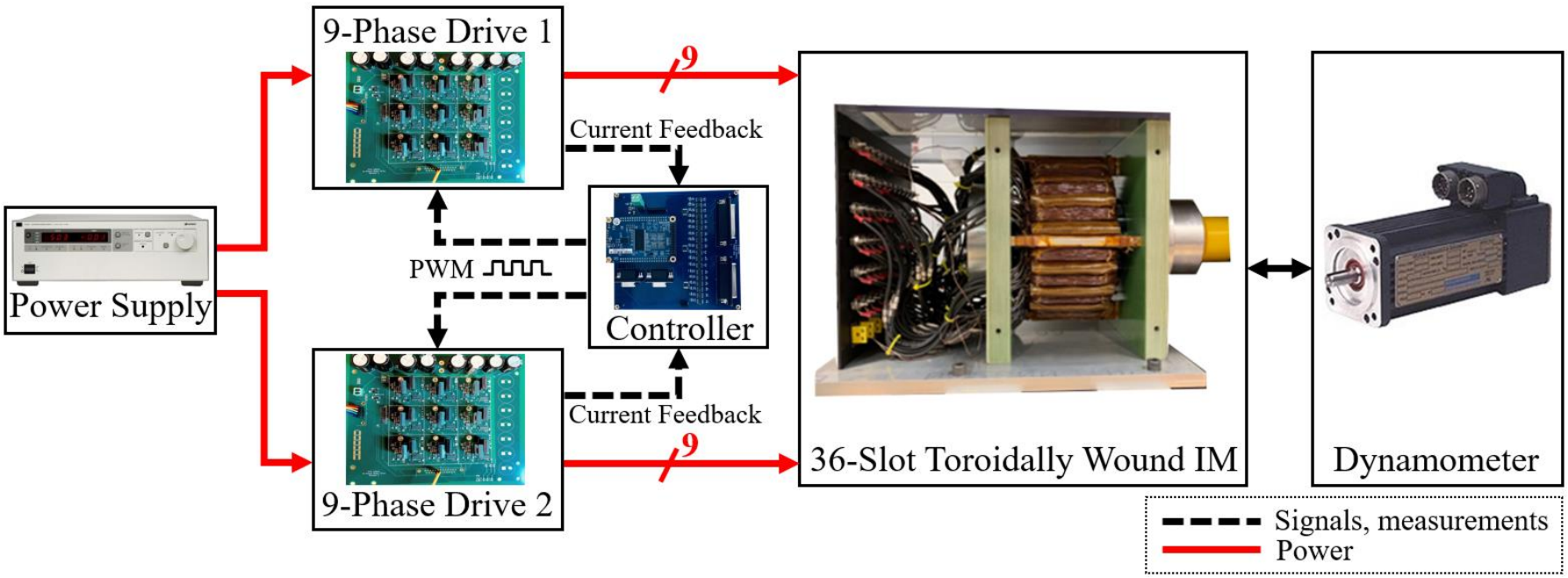


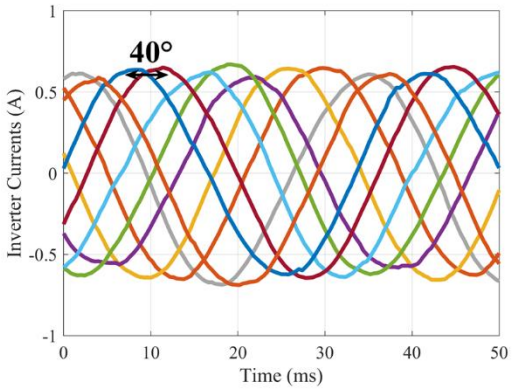
Loss minimization using variable-pole IM

Can we reduce losses in a real machine?

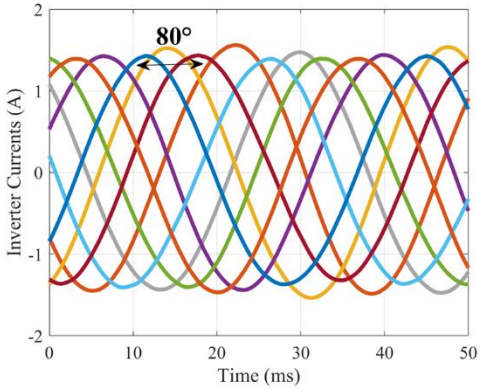
Experimental Setup



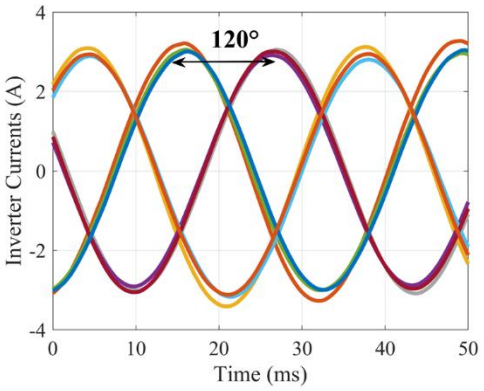
Experimental Setup



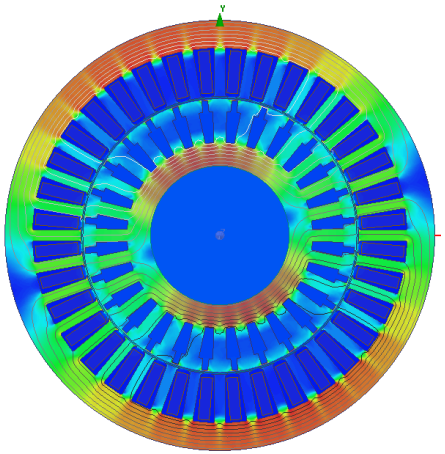
(a)



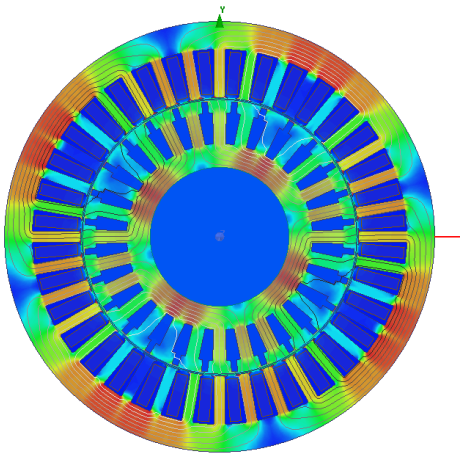
(b)



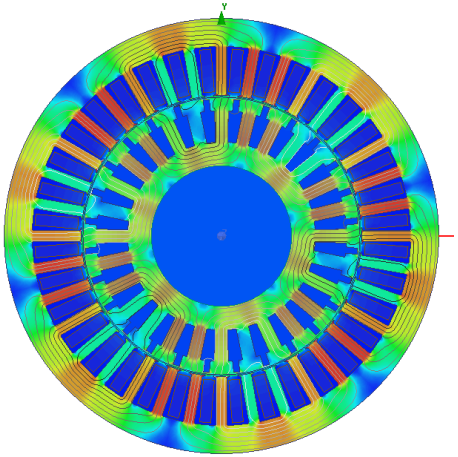
(c)



2-Pole



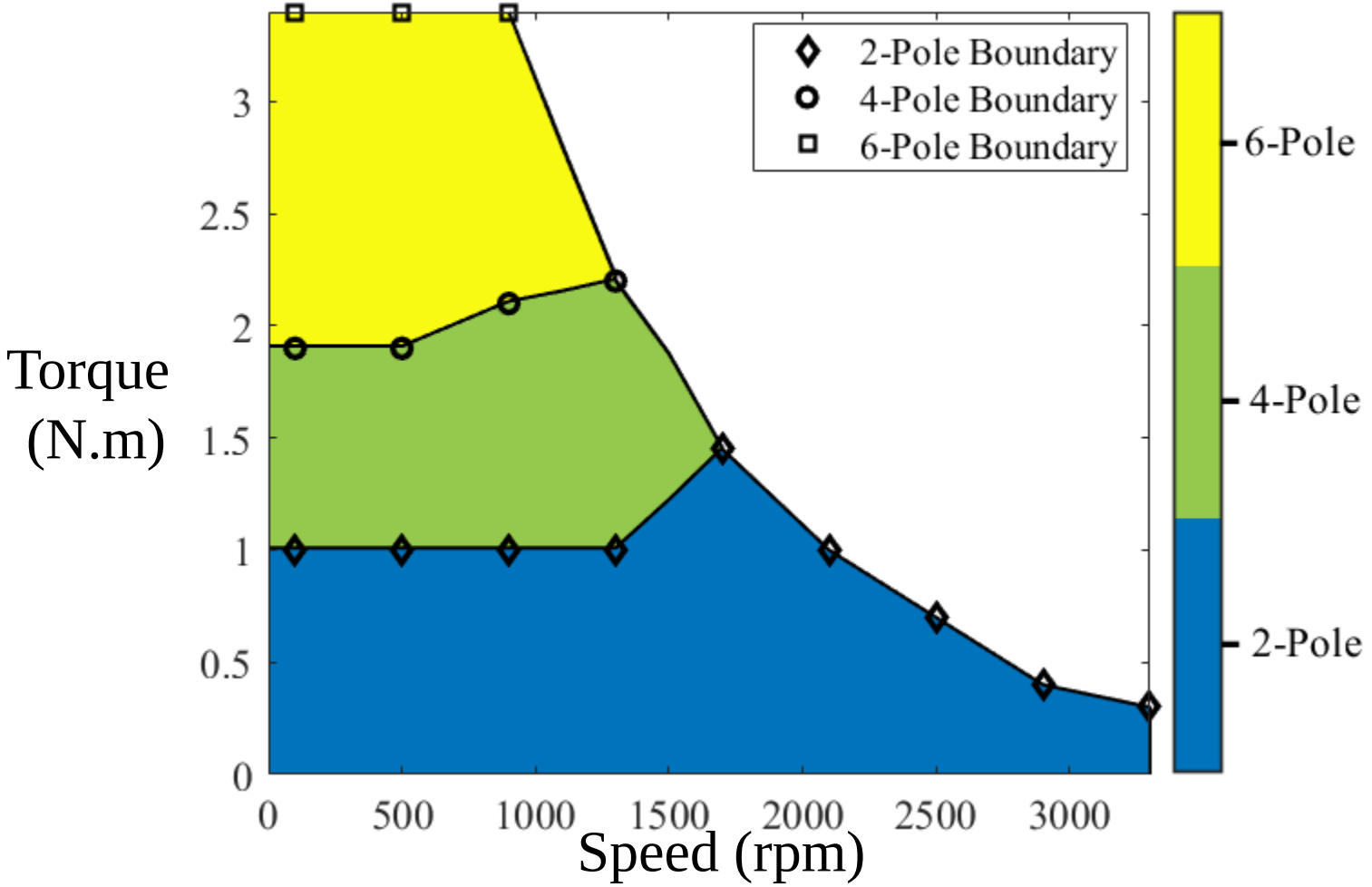
4-Pole



6-Pole

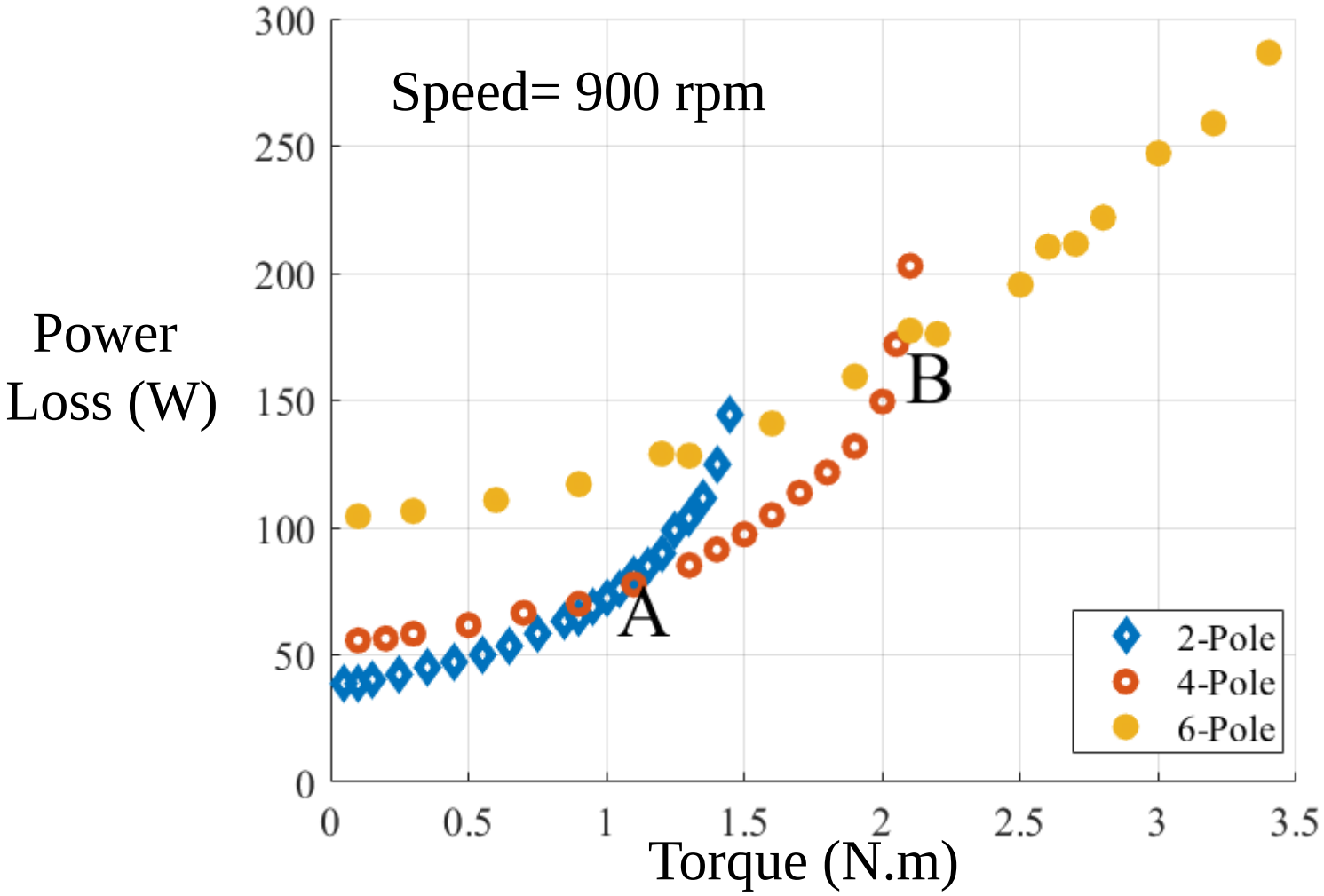
Experimental pole colormap

Low pole counts are the best choice for light load and high speed.



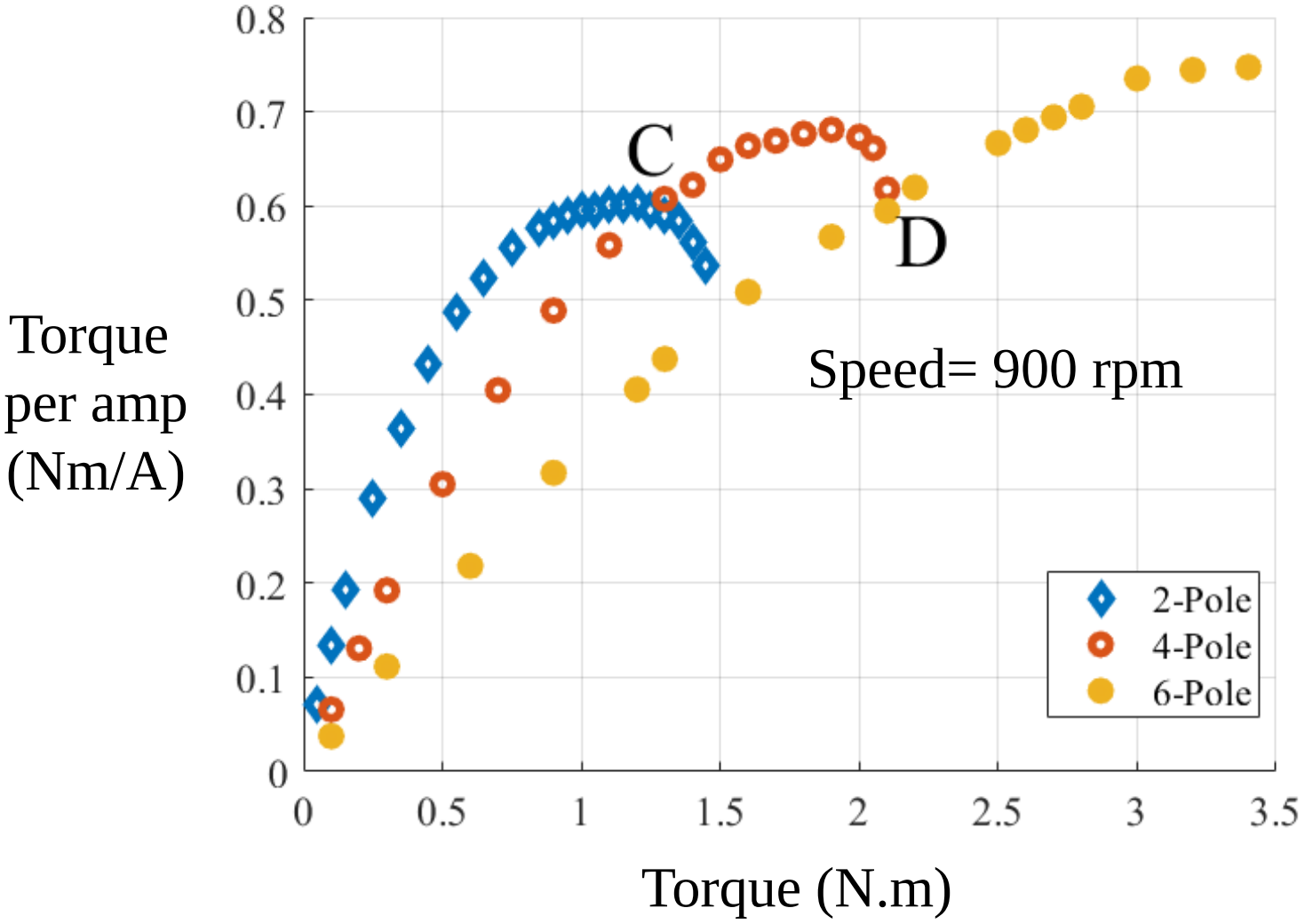
Experimental results

Experimental loss minimization using pole count.



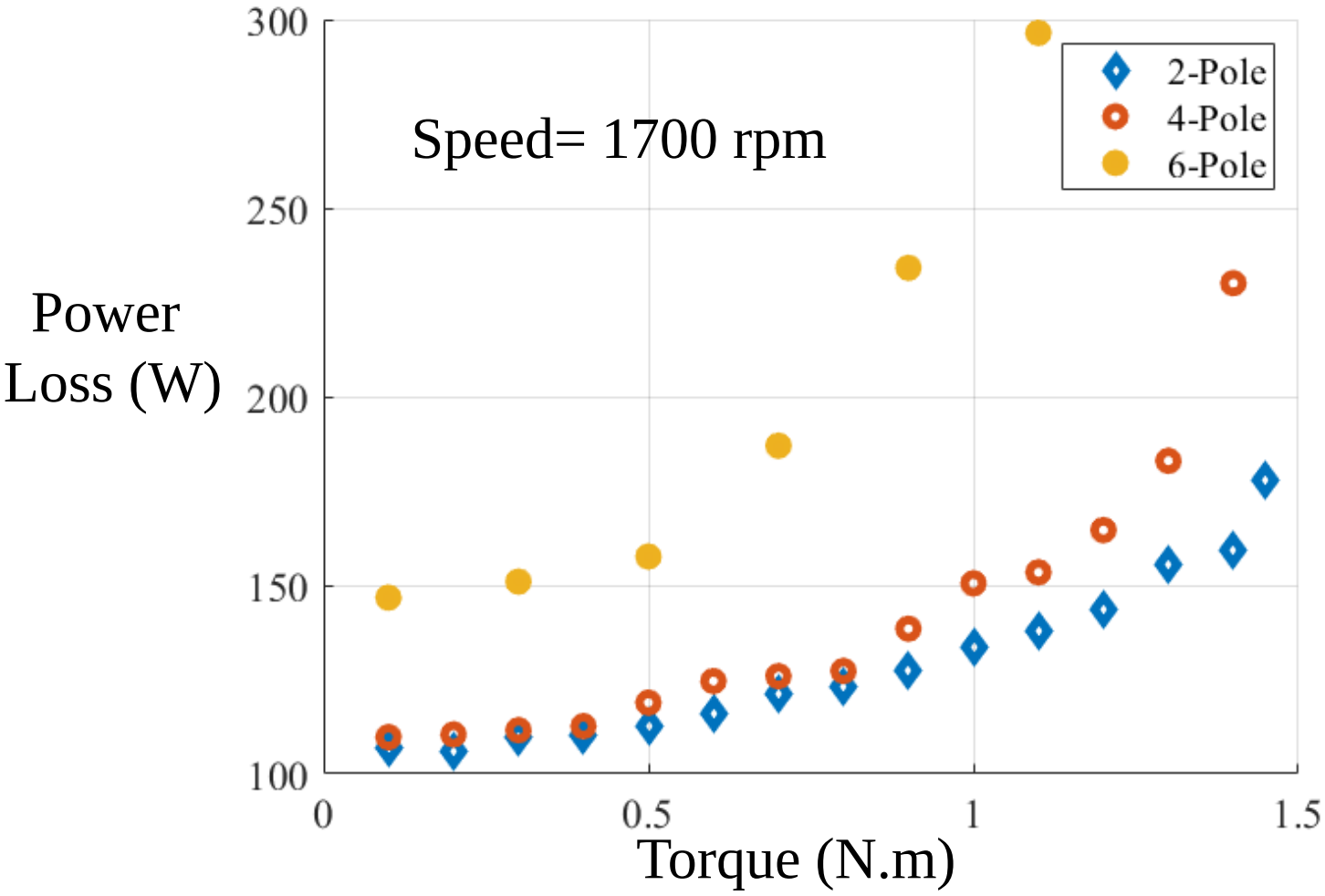
Experimental results

Experimental stator current minimization using pole count.

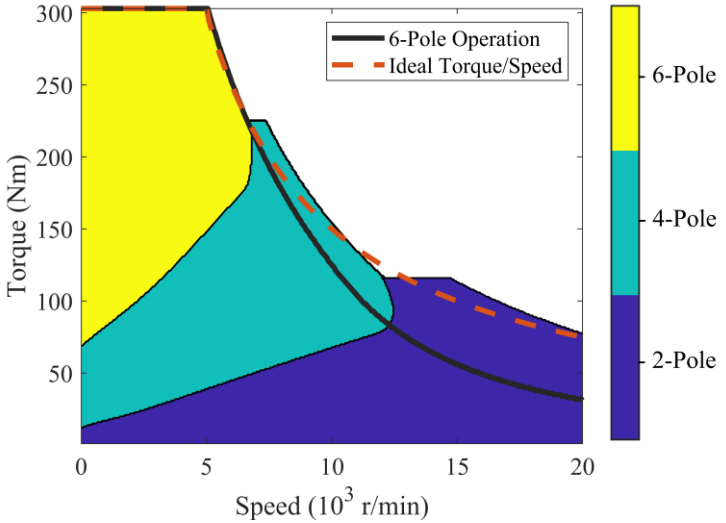


Experimental results

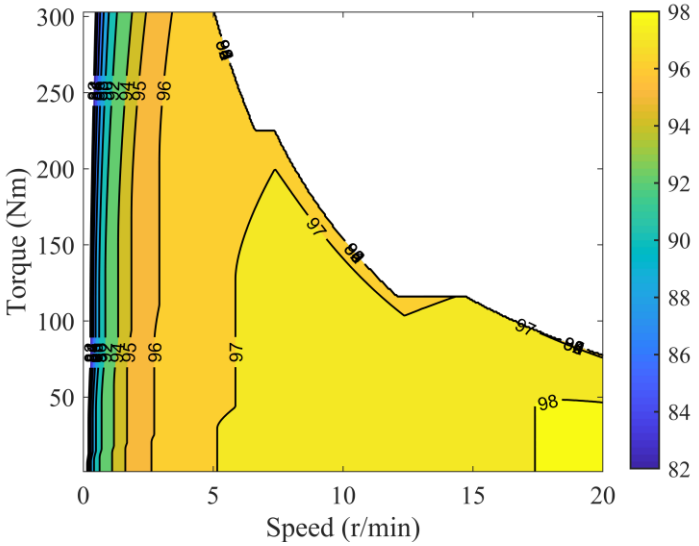
Lower pole count improve high-speed efficiency.



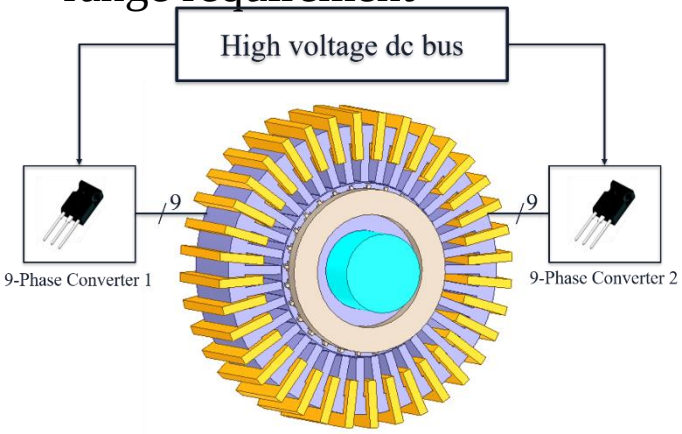
Conclusion



1) Meets EV wide speed-range requirement



2) Better efficiency



3) More efficient and compact system level design

Future Work

1) Currently building a new power-electronics GaN-based 18-phase drive

2) Smooth online pole count transition

3) Possibly building a high-power (100 kW or more) prototype

Publications

1) **E. Libbos**, B. Ku, S. Agrawal, S. Tungare, A. Banerjee and P. T. Krein, "Loss Minimization and Maximum Torque-Per-Ampere Operation for Variable-Pole Induction Machines," in IEEE Transactions on Transportation Electrification, vol. 6, no. 3, pp. 1051-1064, Sept. 2020.

2) **E. Libbos**, B. Ku, S. Agrawal, S. Tungare, A. Banerjee and P. T. Krein, "Variable-Pole Induction Machine Drive for Electric Vehicles," 2019 IEEE International Electric Machines & Drives Conference (IEMDC), San Diego, CA, USA, 2019, pp. 515-522.

3) **E. Libbos**, R. Hao, B. Ku, A. Banerjee and P. T. Krein, "Modular Multiphase Drives for Variable-Pole Induction Machines in Electric Vehicles," 2020 IEEE Applied Power Electronics Conference and Exposition (APEC), New Orleans, LA, USA, 2020, pp. 696-703.

4) B. Ku, Y. Tian, S. Wang, **E. Libbos**, S. Agrawal and A. Banerjee, "A Distributed and Scalable Electromechanical Actuator for Bio-Inspired Robots," 2019 IEEE International Electric Machines & Drives Conference (IEMDC), San Diego, CA, USA, 2019, pp. 2180-2187.

5) D. Lee, S. Sirimanna, P. Huynh, **E. Libbos**, A. Banerjee, K. Haran, “Slotless-PM Machine Design for an Integrated Generator-Rectifier Architecture for Off-Shore Wind Turbines” in IEEE Journal of Emerging and Selected Topics in Power Electronics. (IN REVIEW).

Thank you !

Questions