

# Modular Multiphase Drives for Variable-Pole Induction Machines in Electric Vehicles



Presenter: Elie Libbos

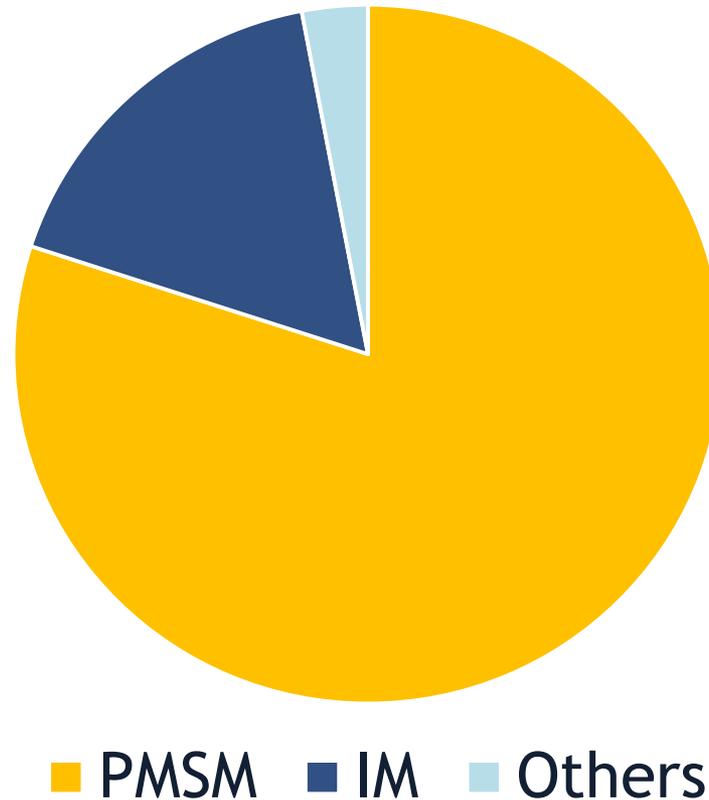
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University of Illinois at Urbana-Champaign

# Permanent magnet synchronous machines dominate the EV industry

Types of machines used in EVs

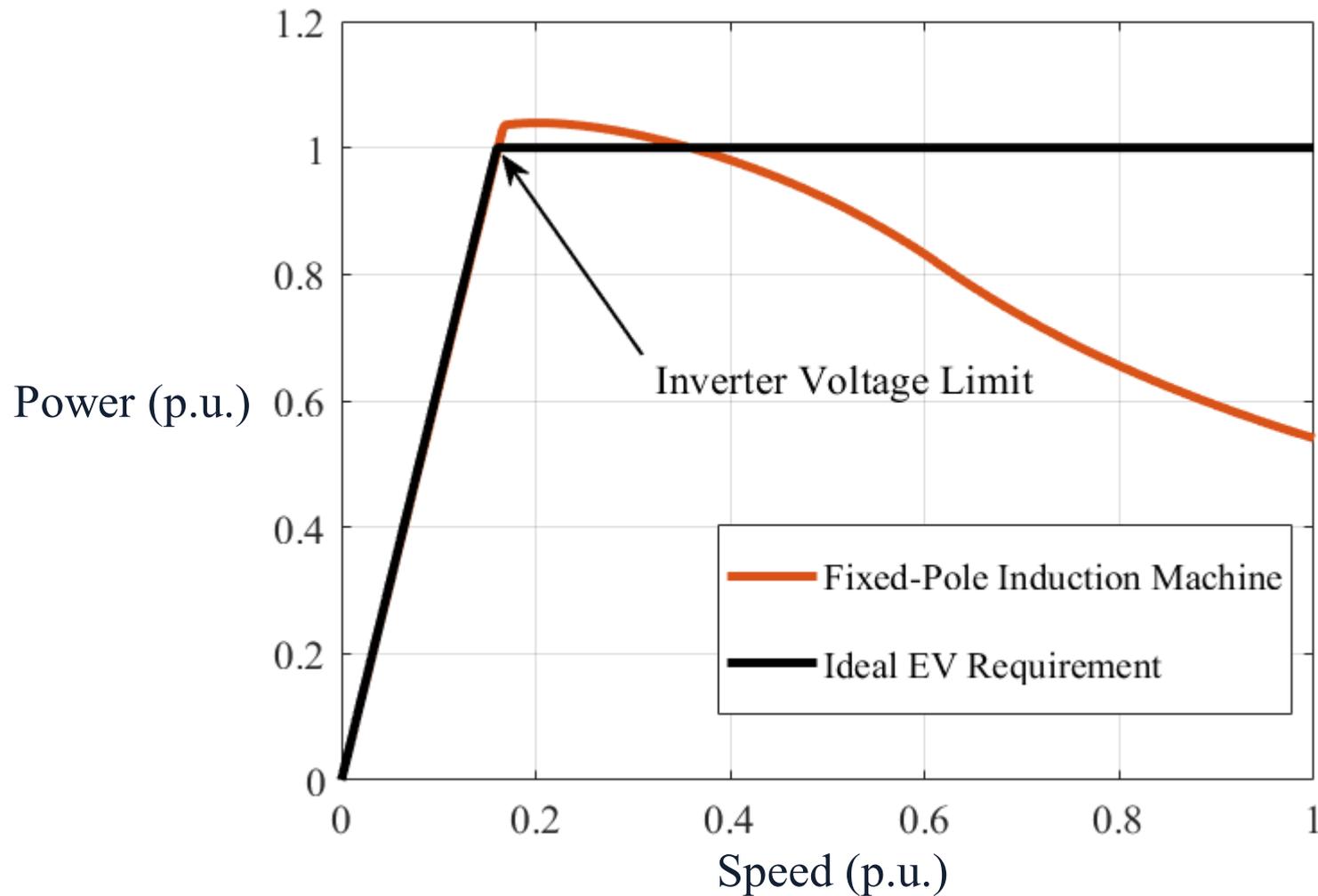


# There is a push towards reducing the dependence on magnets

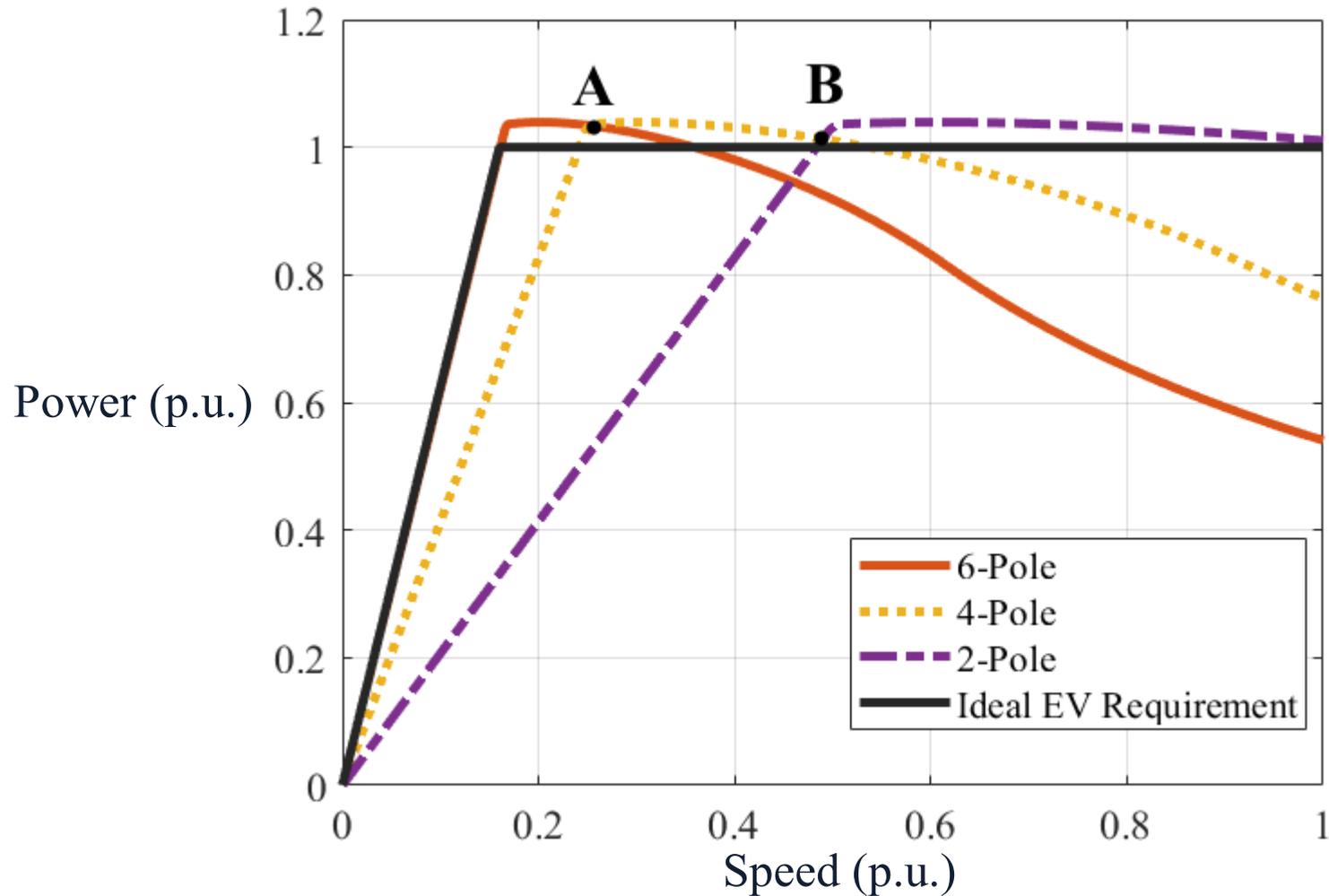


F. Lambert, "Audi launches e-tron electric SUV with \$74,800 starting price," 2018. [Online]. Available: <https://electrek.co/2018/09/17/audilaunches-e-tron-electric-suv-with-74000-starting-price/>. [Accessed: 05-Dec-2018]

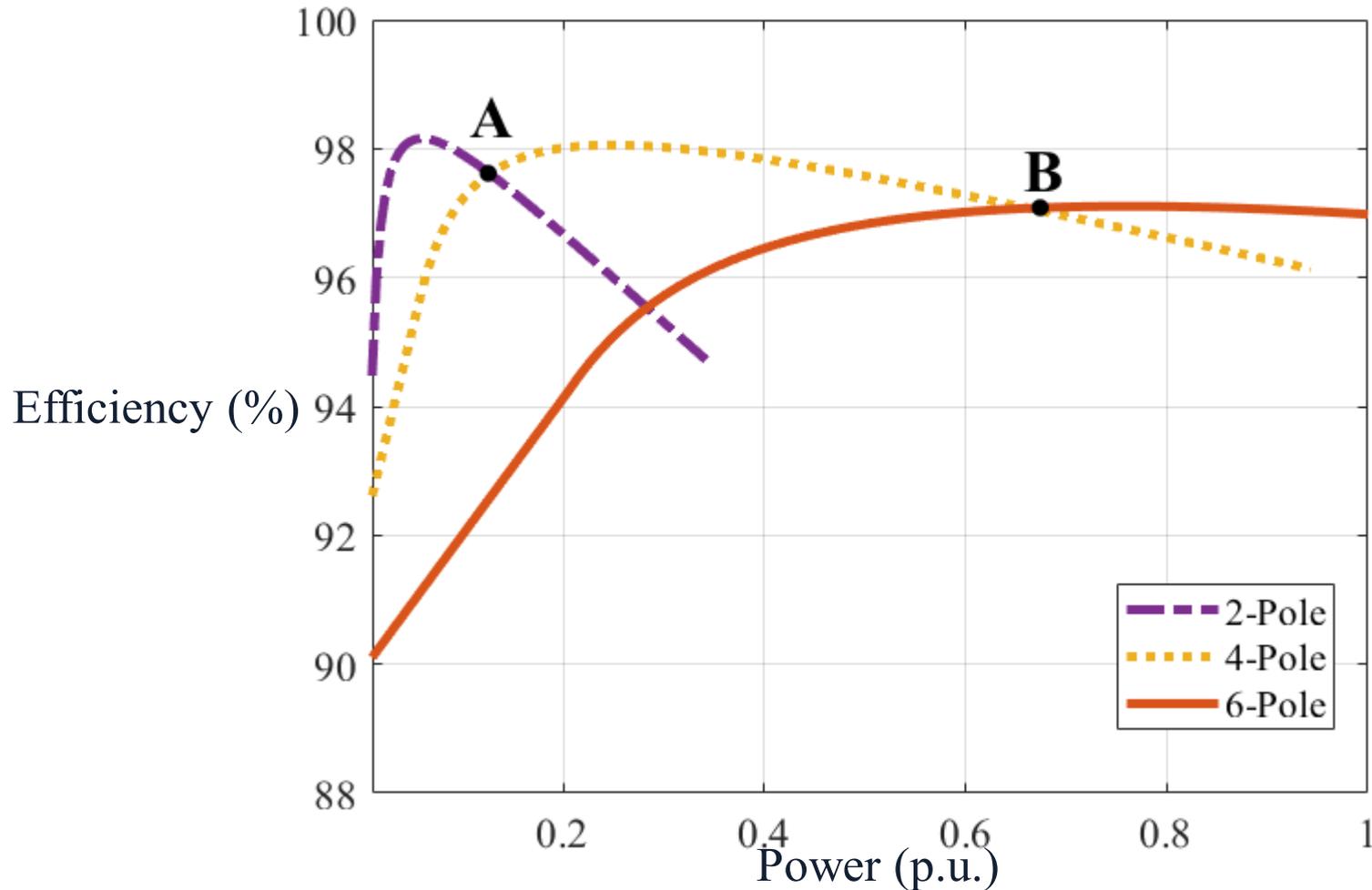
# The machine power capability drops below rated capability due to flux weakening



# Variable-pole induction machines maintain rated power capability over wide speed range



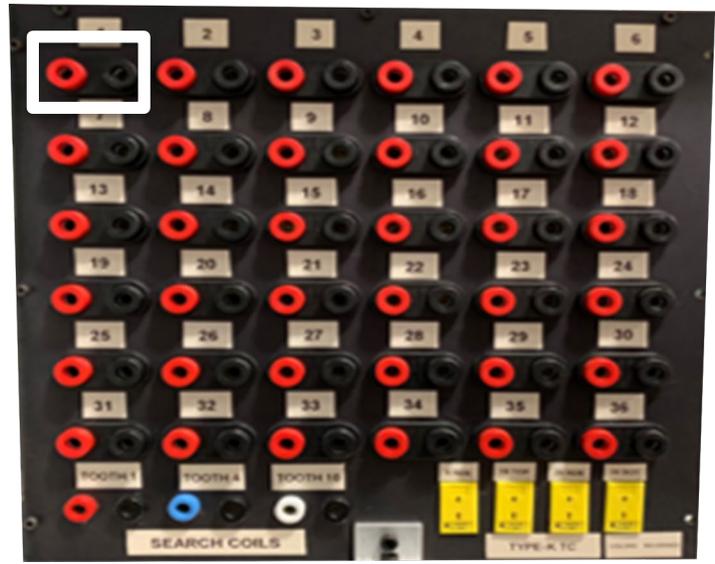
# Variable-pole operation improves machine efficiency at partial loading



Machine slot conductors are building blocks that can be series/parallel grouped

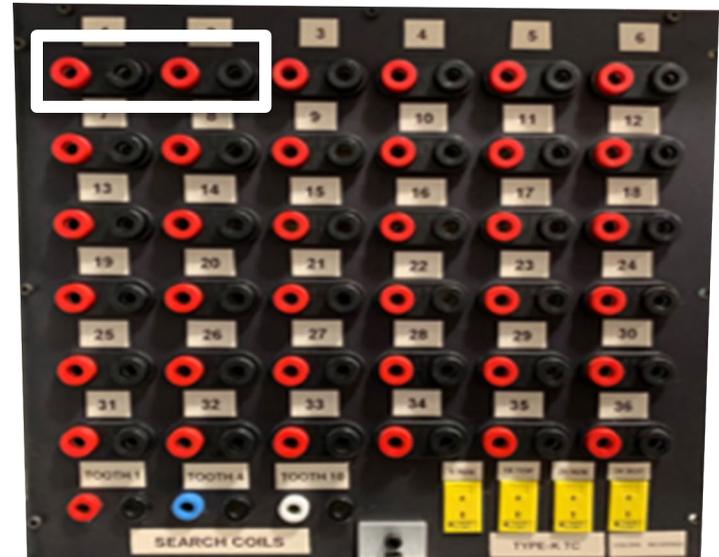


a) Machine side view



b) Individual slot access

The number of independent currents reduces as slots are grouped



# Example: Grouping slots of phase A to operate the machine as 3-phase

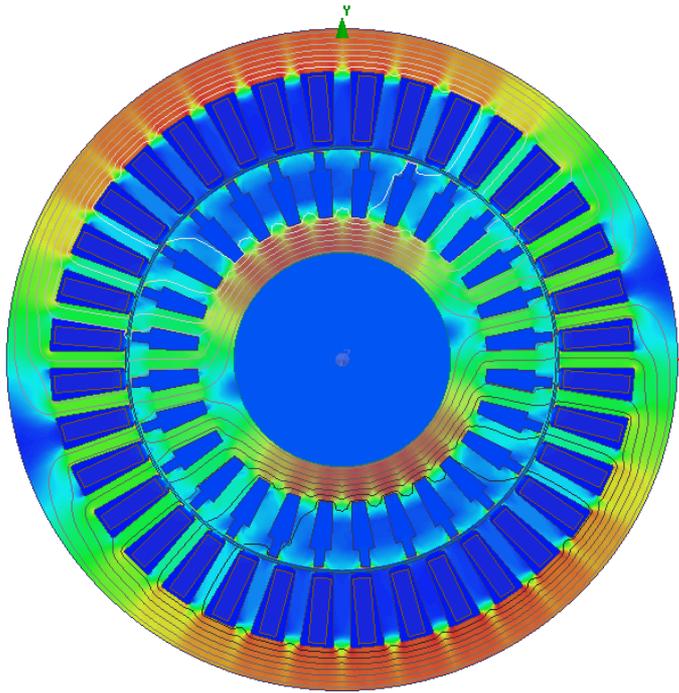


a) Machine side view

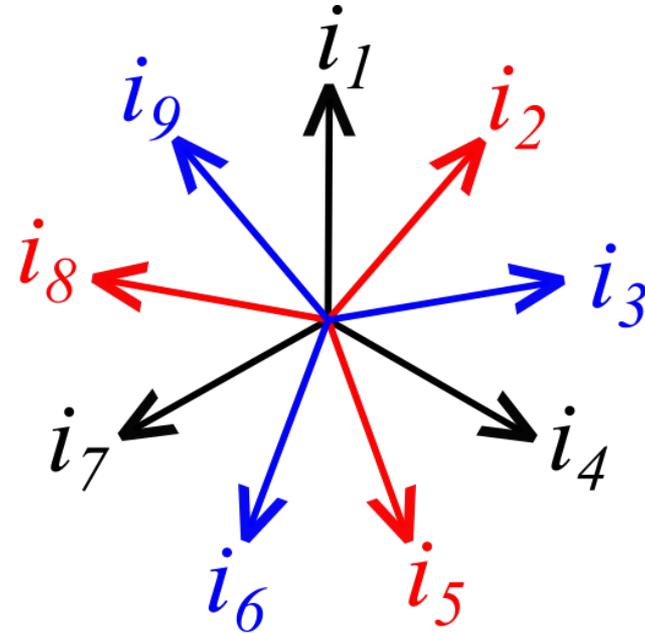


b) Individual slots

# 9-Leg drive example: 9-phase/2-pole operation

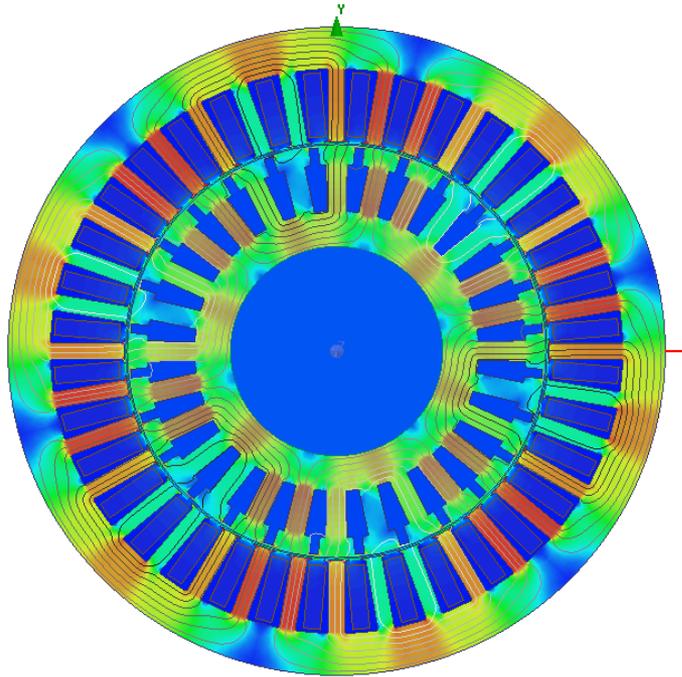


2-Pole

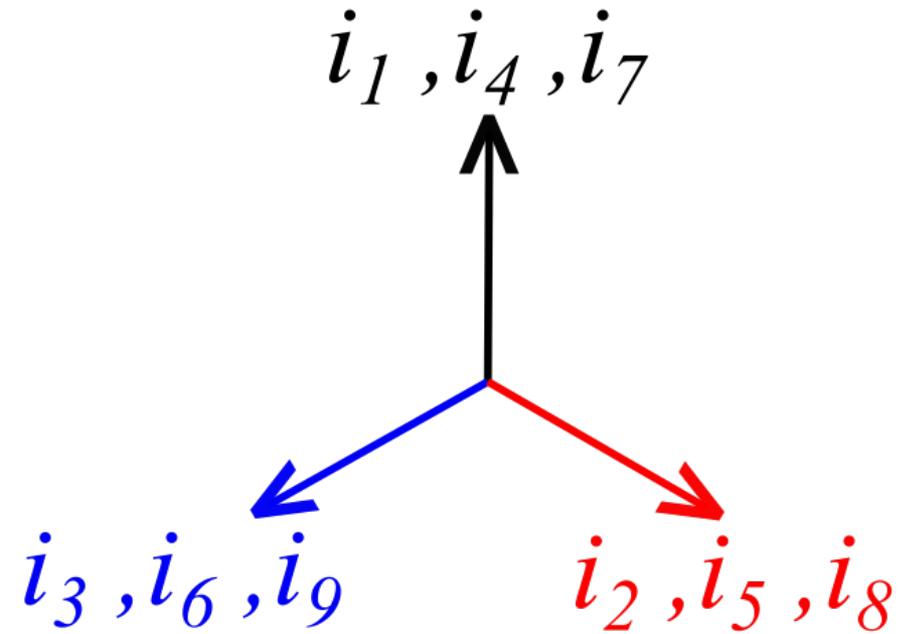


9-Phase

Electronic Pole-Changing is done by changing the excitation phase number (3-phase/6-pole)

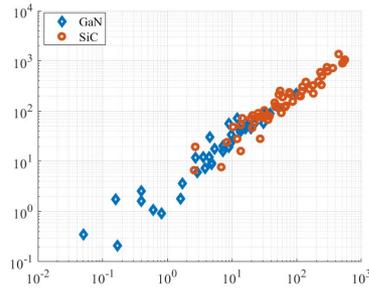


6-Pole

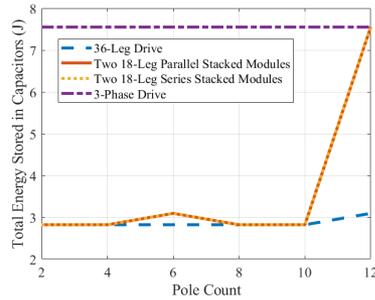


3×3-Phase

# Outline



## Effect of Drive Architecture on Inverter Losses

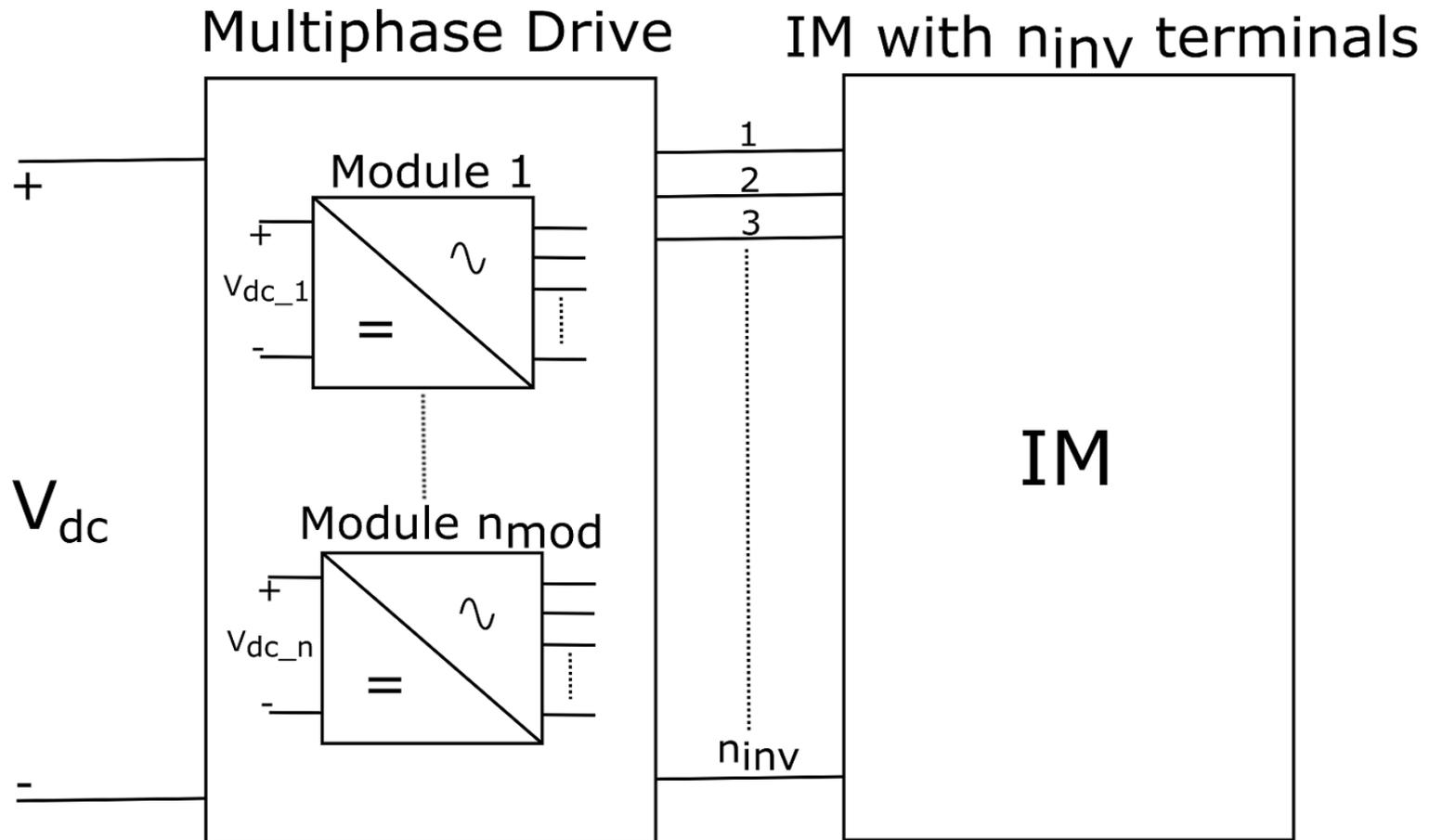


## Filter Capacitor Sizing

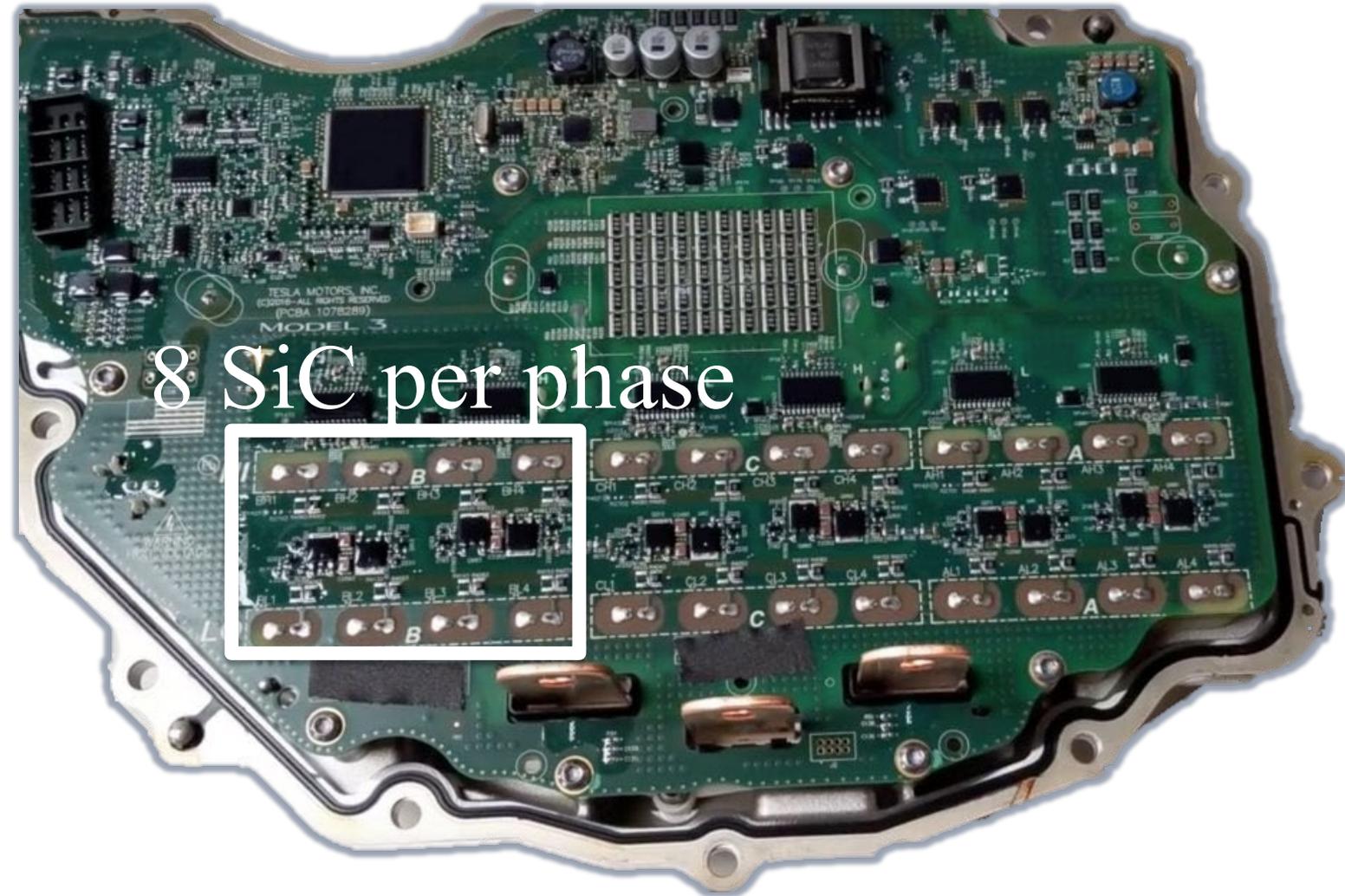


## Experimental Results

A high number of inverter legs is needed to change pole count

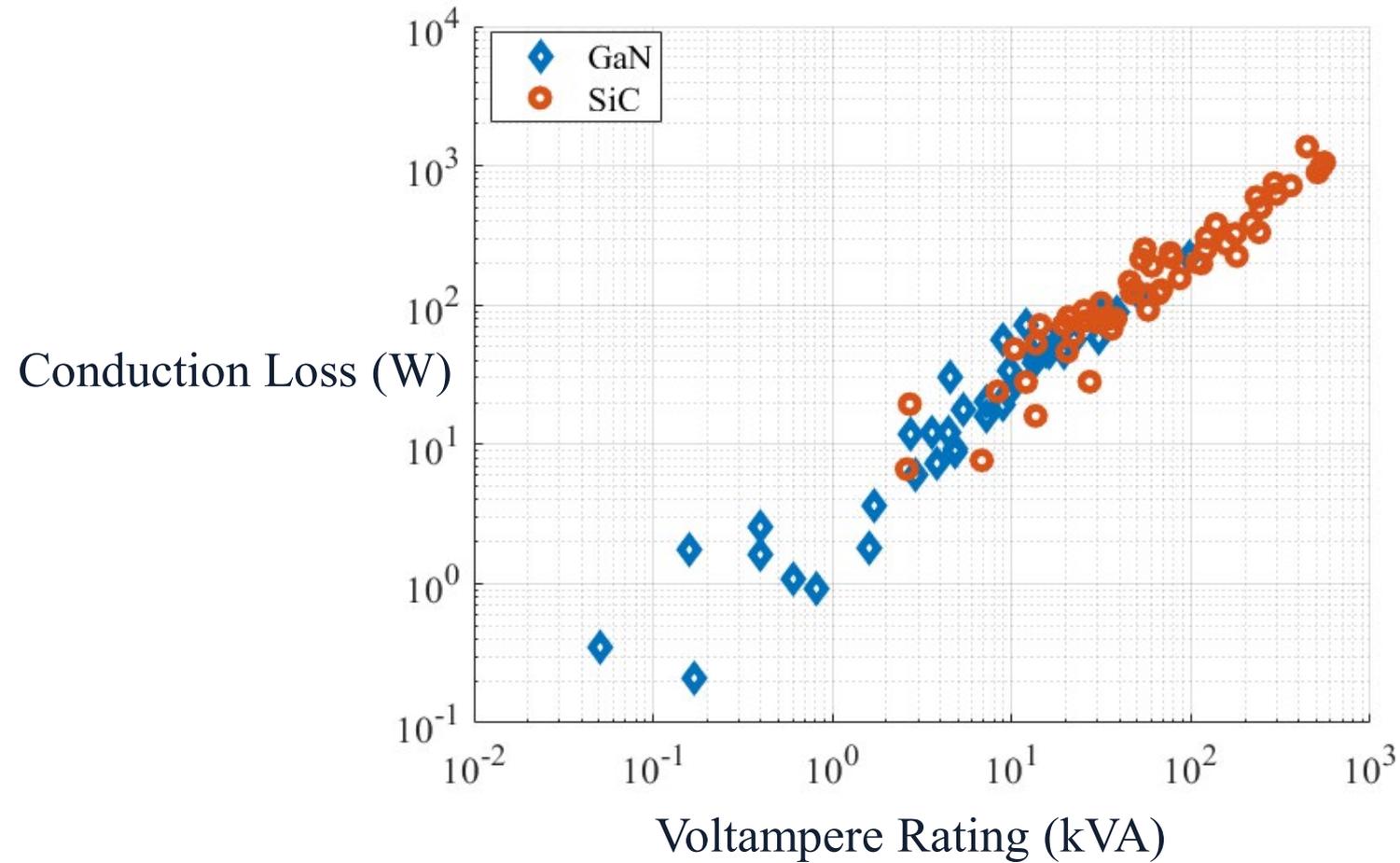


# Tesla Model 3 Inverter uses 24 SiC devices

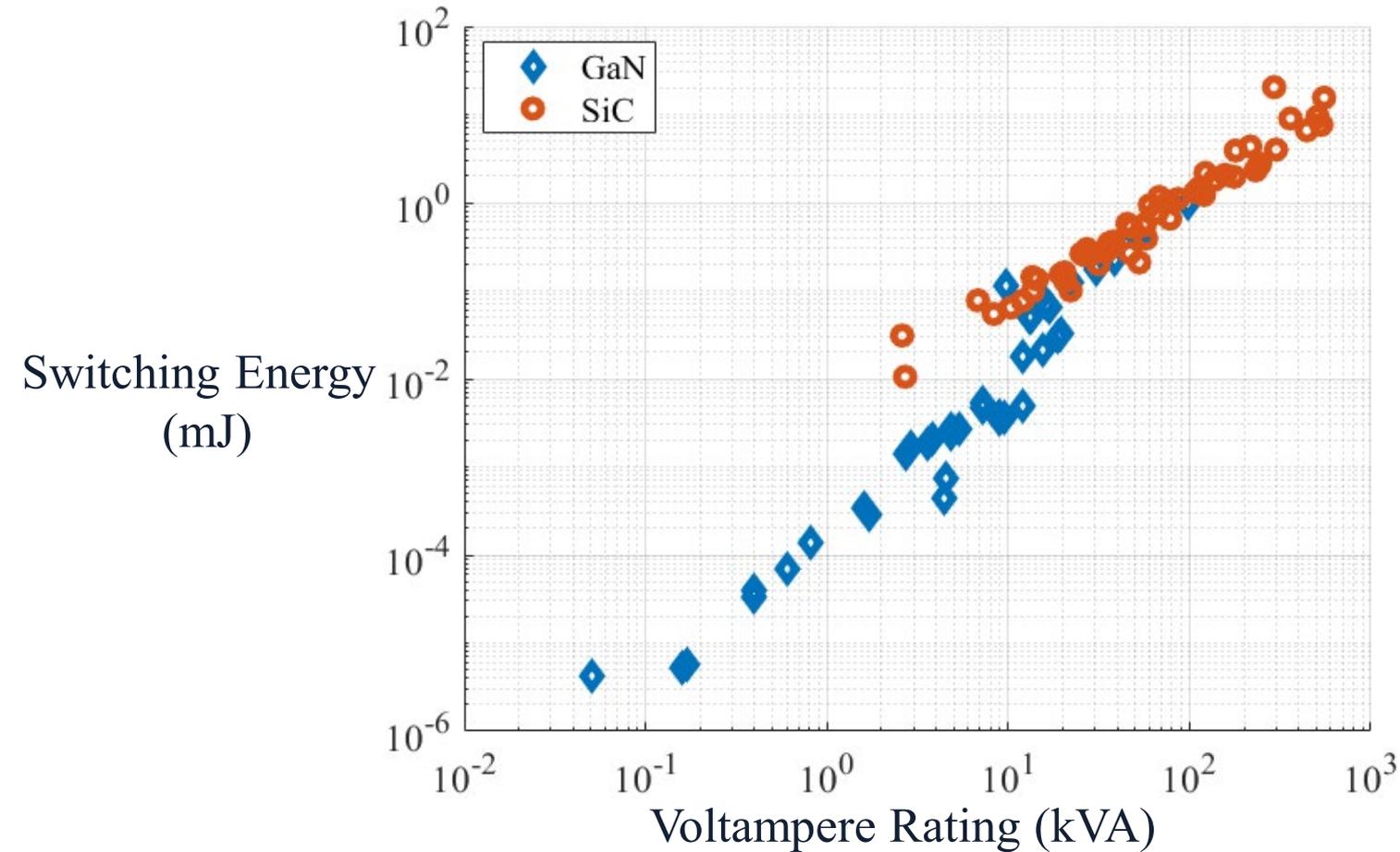


8 SiC per phase

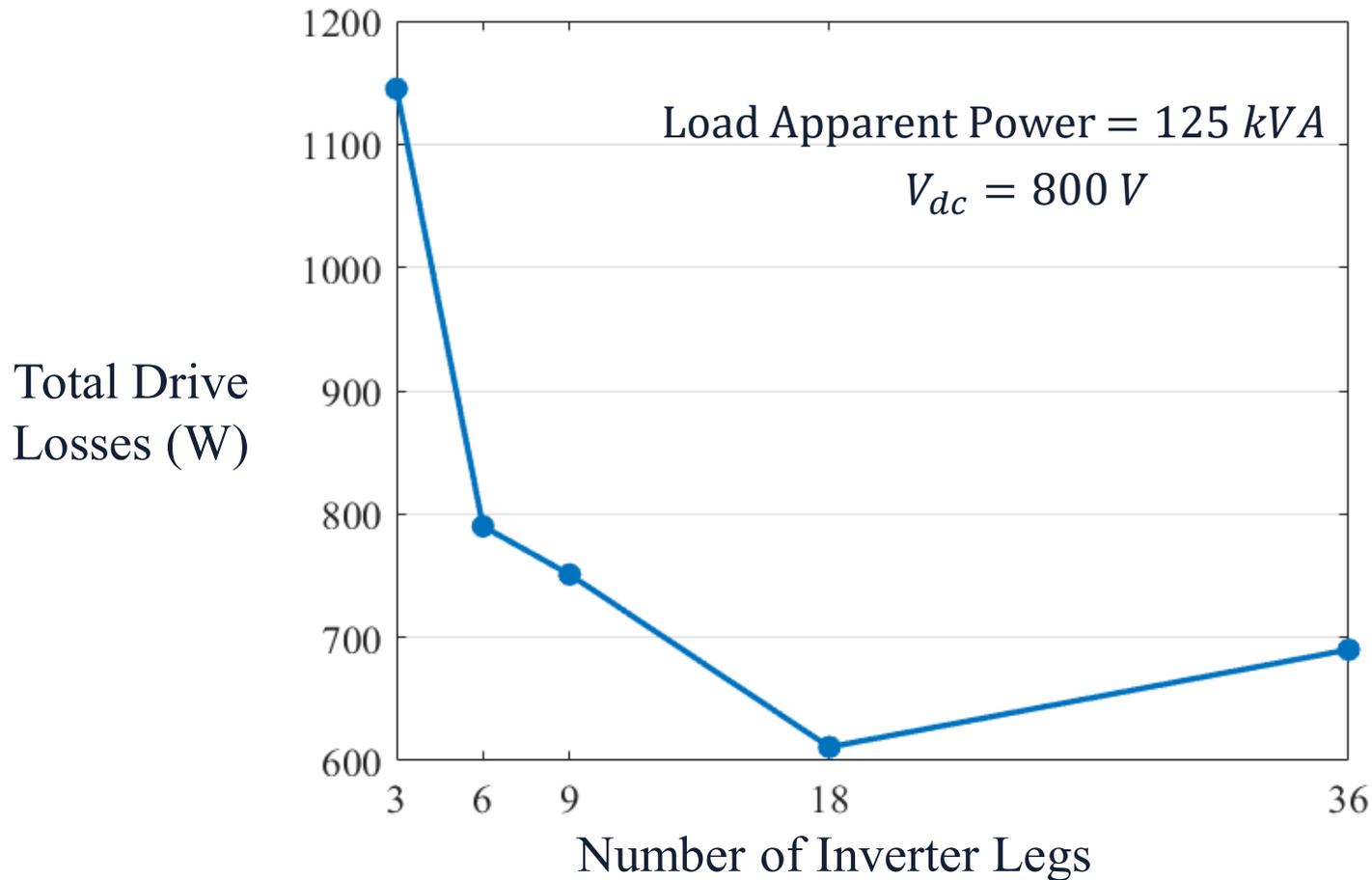
# Conduction loss in a device generally increases with its Voltampere rating



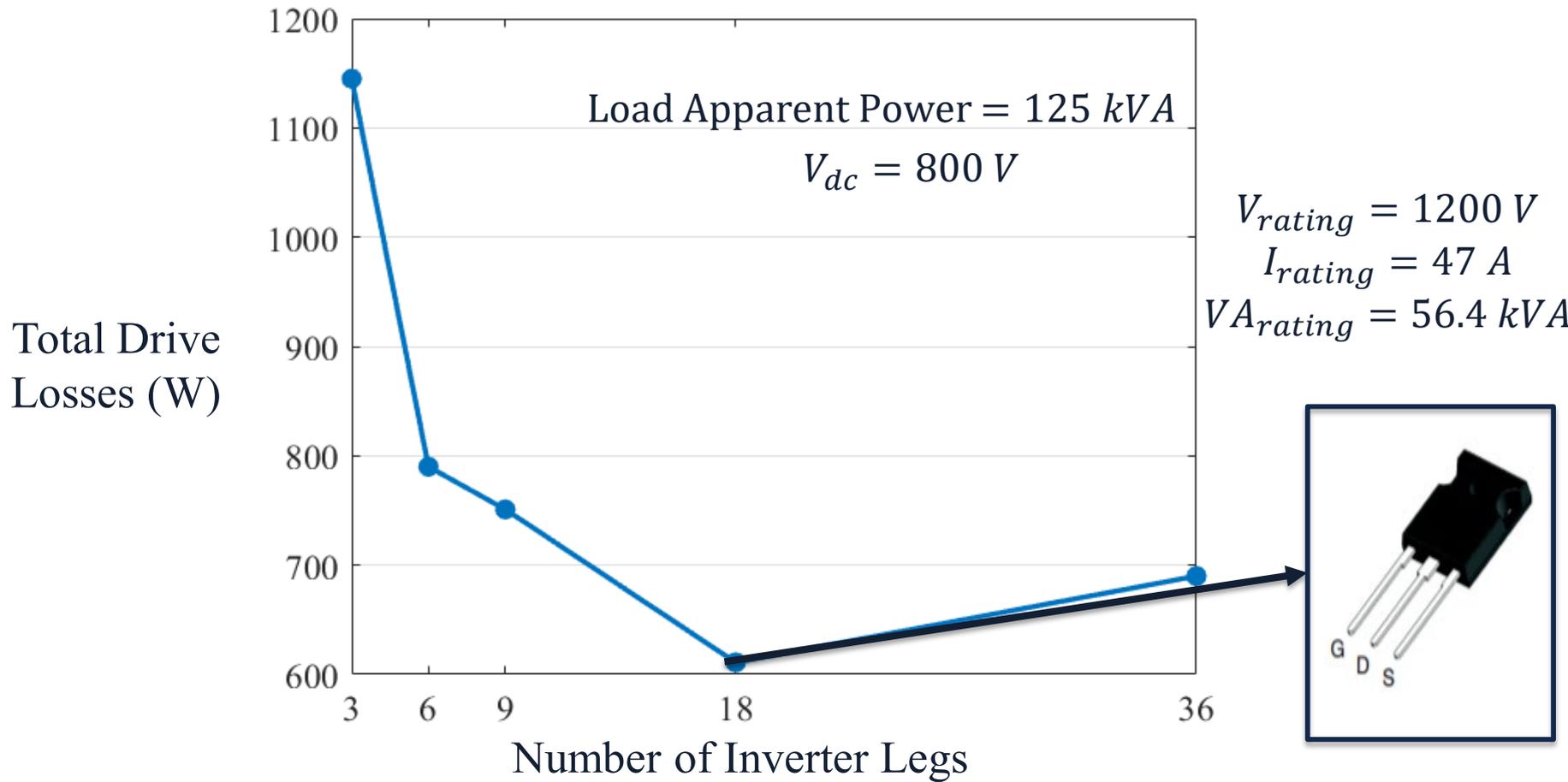
# Switching energy in a device generally increases with its Voltampere rating



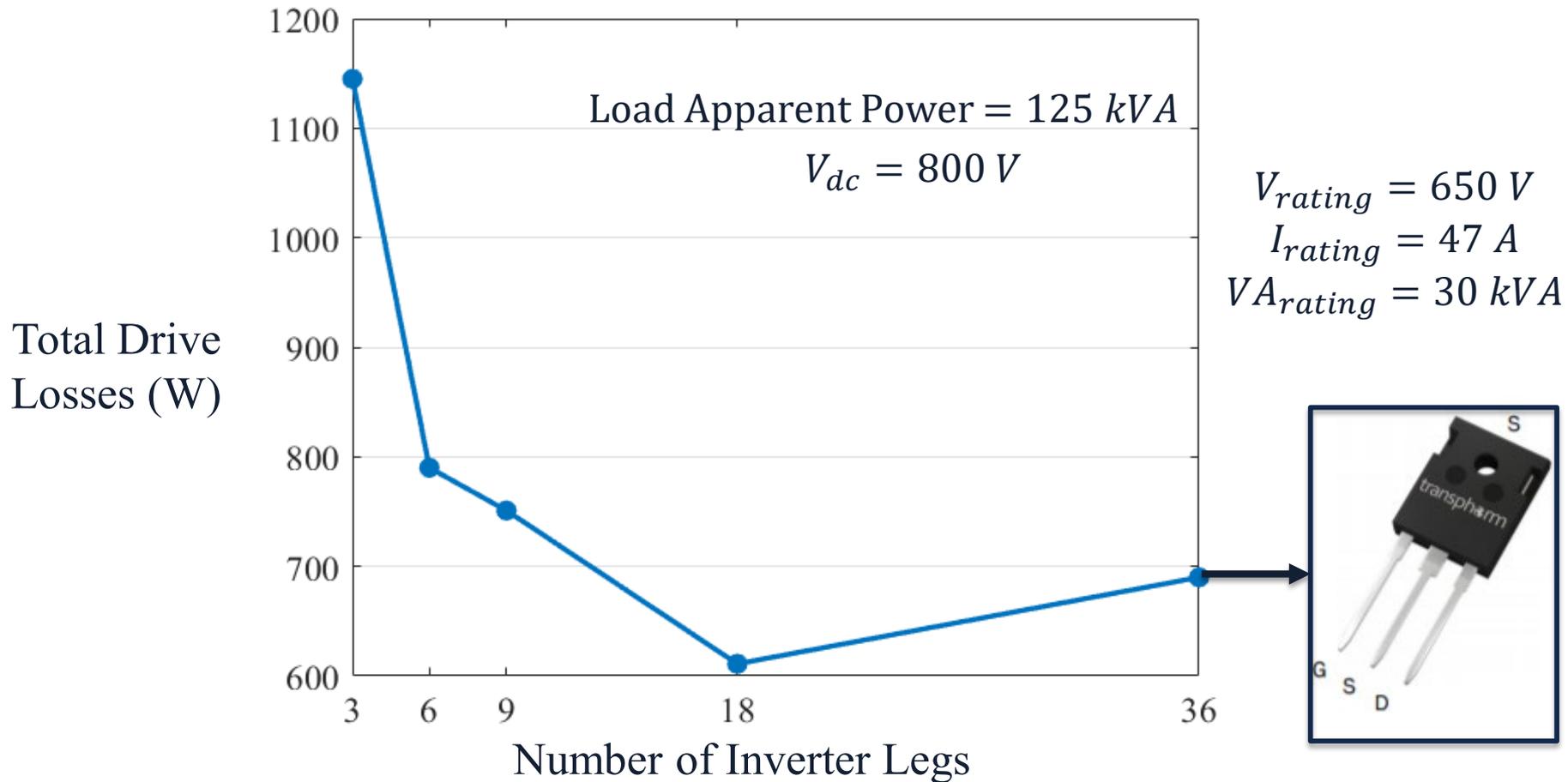
# Total drive losses can be optimized with respect to number of inverter legs



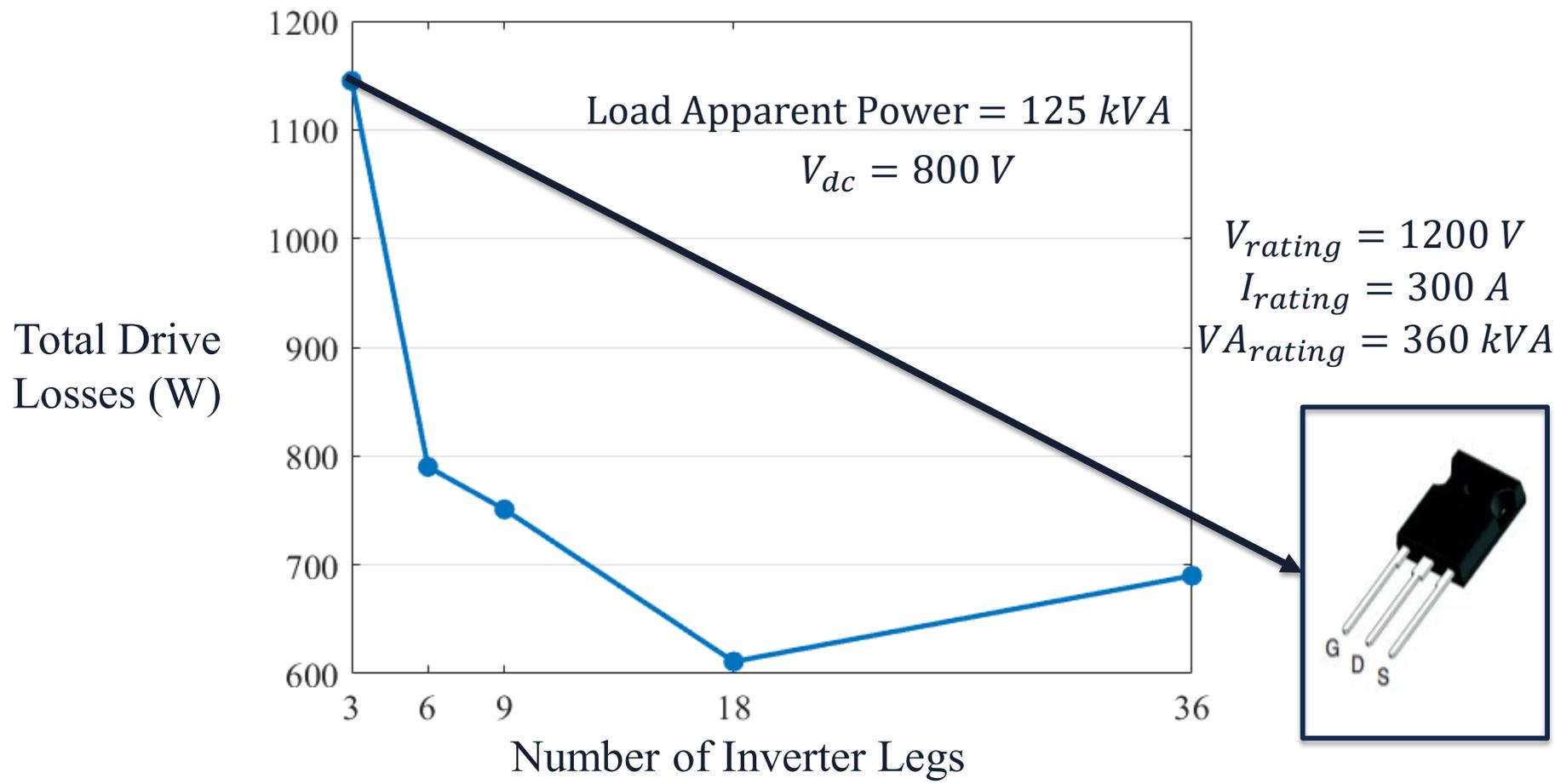
# The 18-leg drive utilizes 1200 V SiC devices



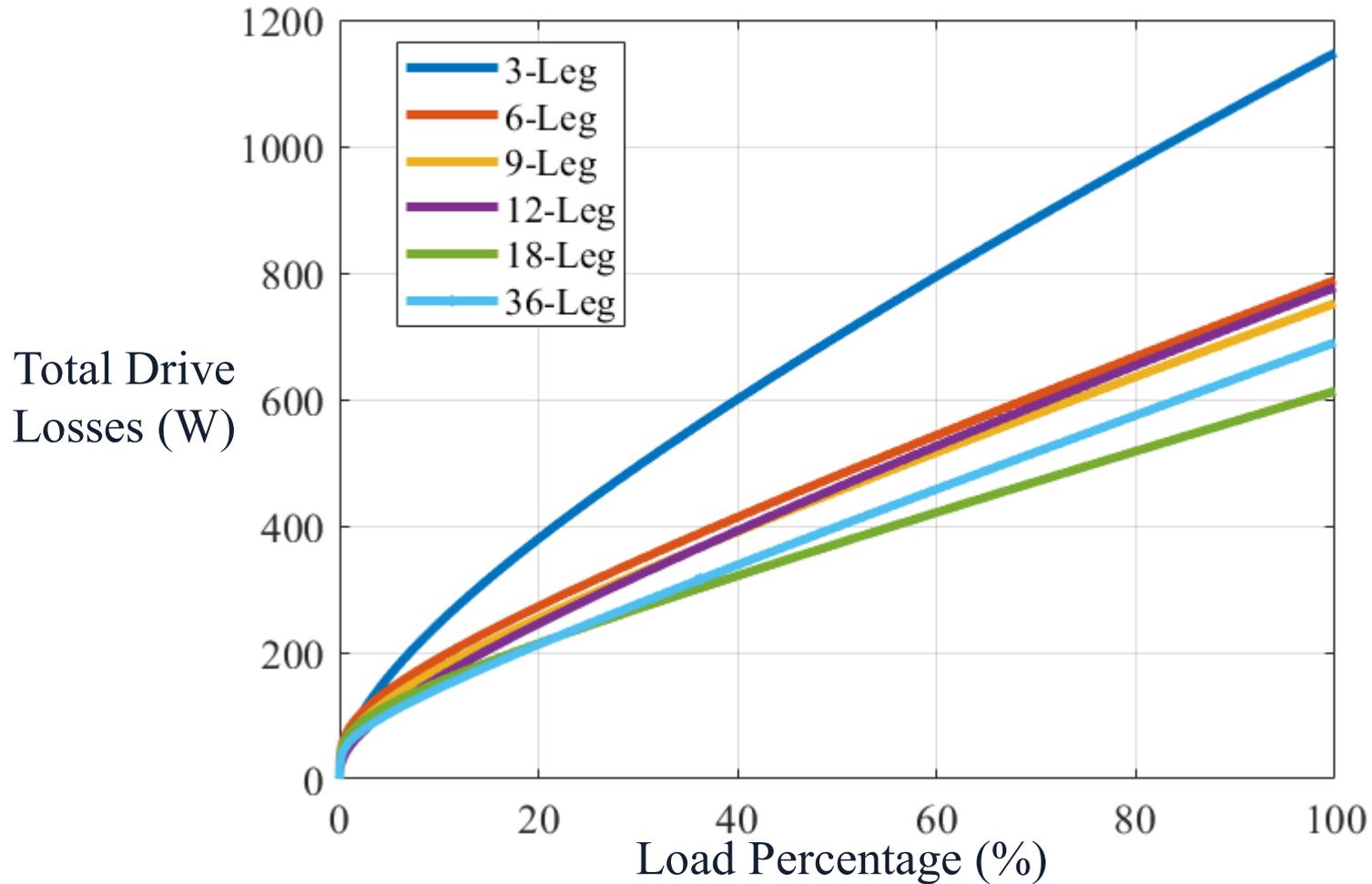
The 36-leg drive utilizes 650 V GaN devices by series stacking the dc side two 18-leg modules



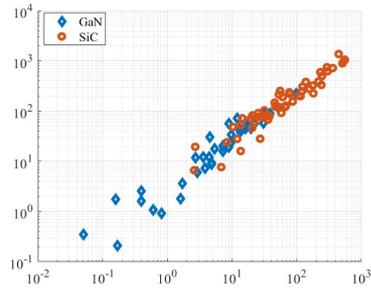
# Low number of high kVA rated devices is required for the conventional 3-phase drive



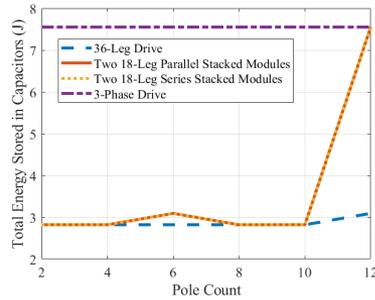
# The 3-leg drive has the highest losses over almost the entire load range



# Outline



## Effect of Drive Architecture on Inverter Losses

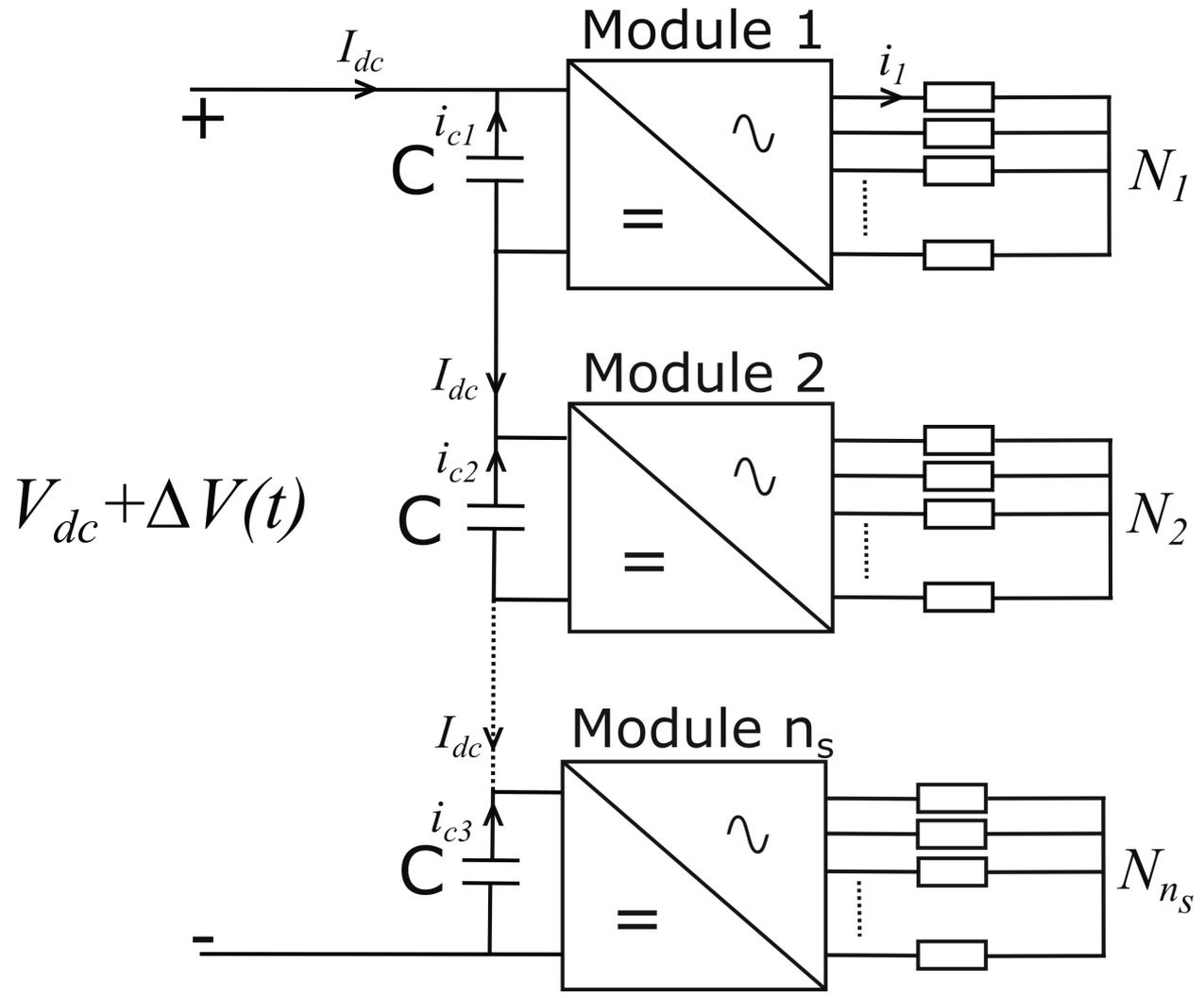


## Filter Capacitor Sizing

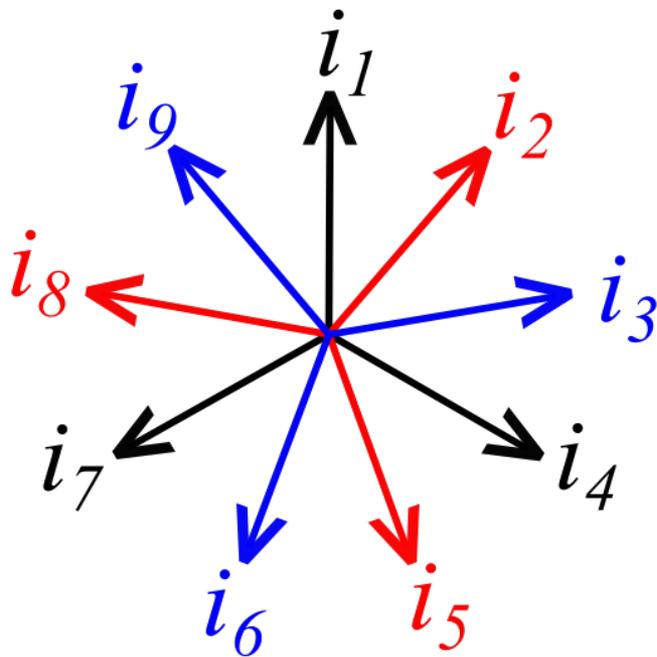


## Experimental Results

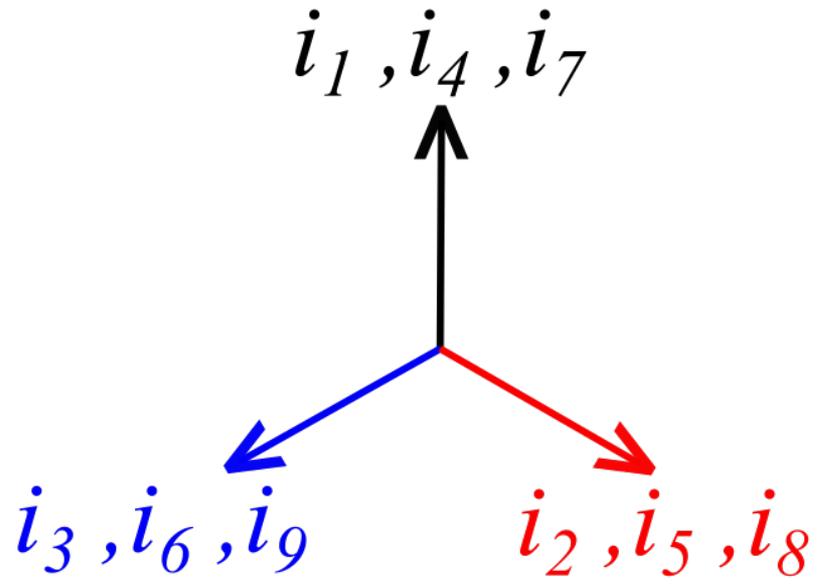
# Schematic of modularized drive



# Phase number changes with pole count

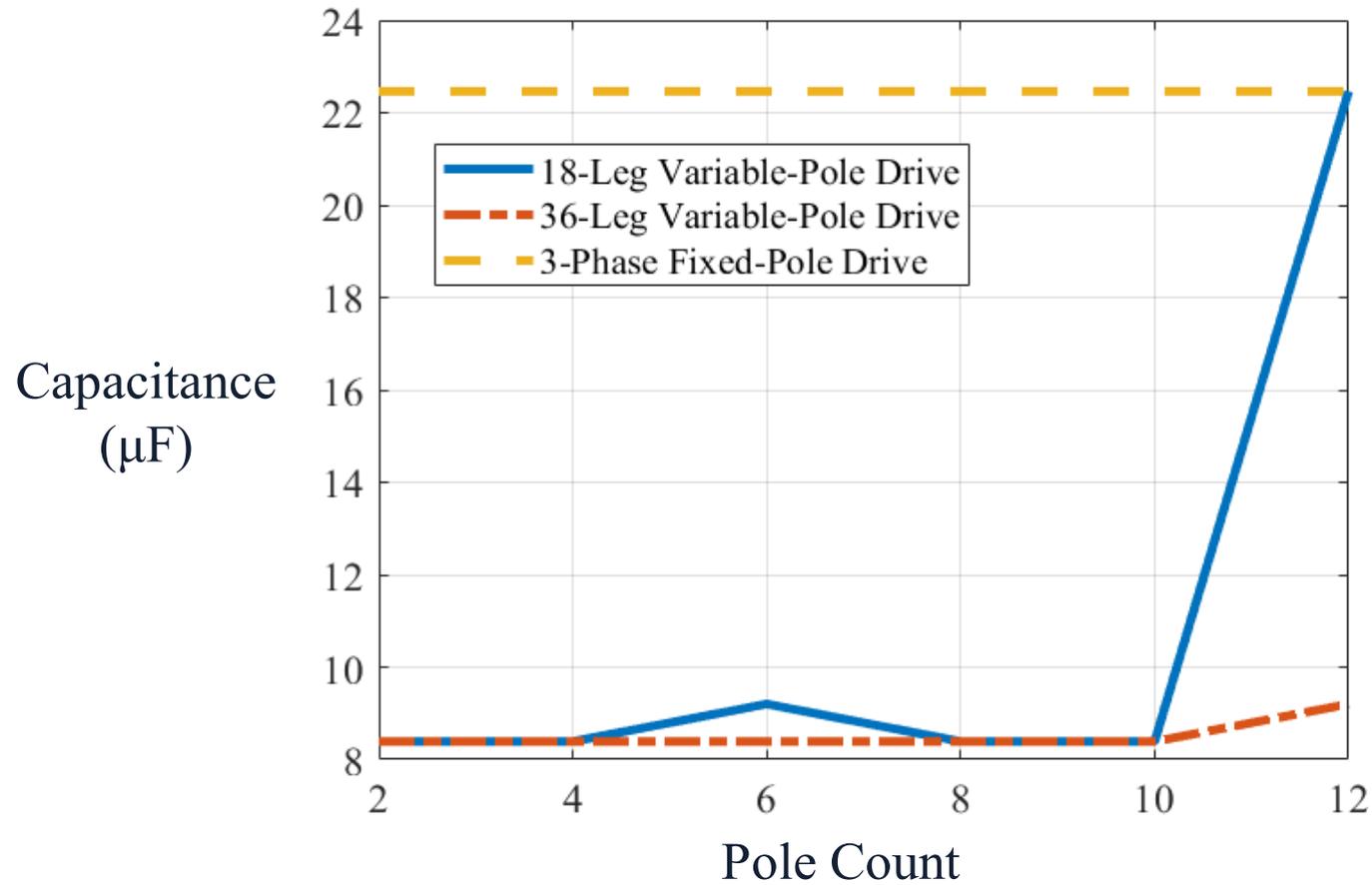


a)  $P$ -pole/9-phase

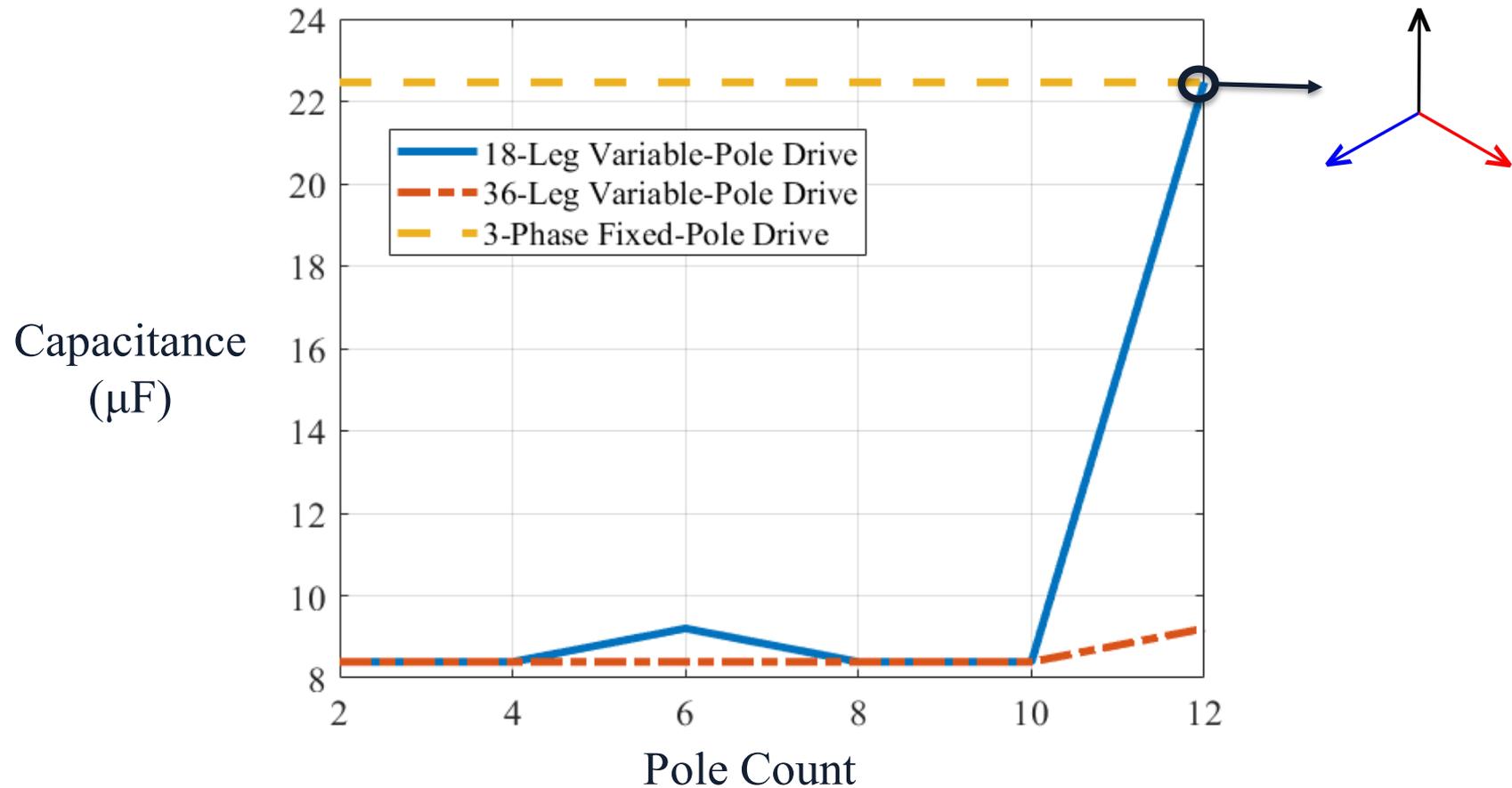


b)  $3P$ -pole/3-phase

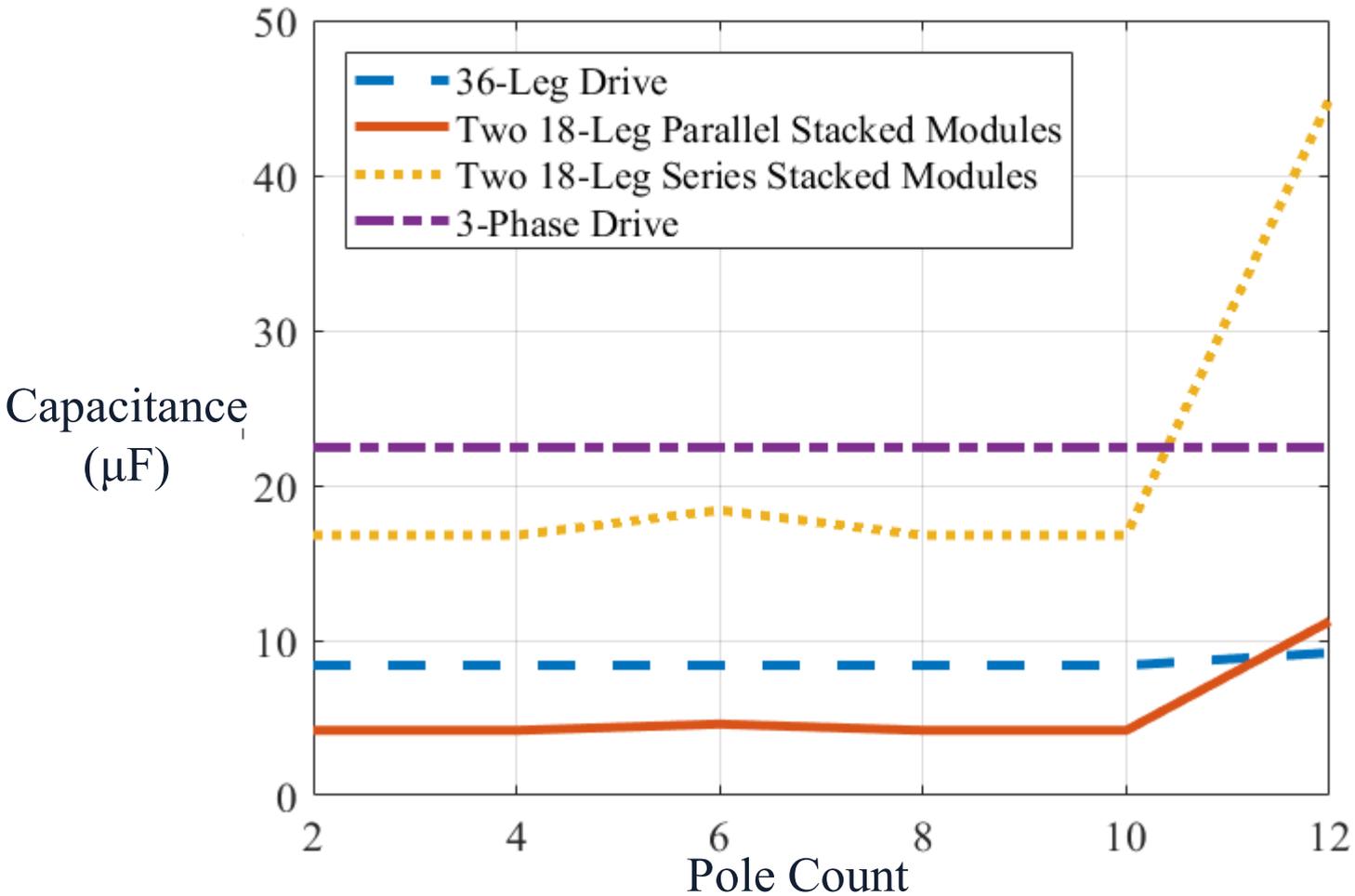
# Increasing the number of inverter legs decreases the capacitance



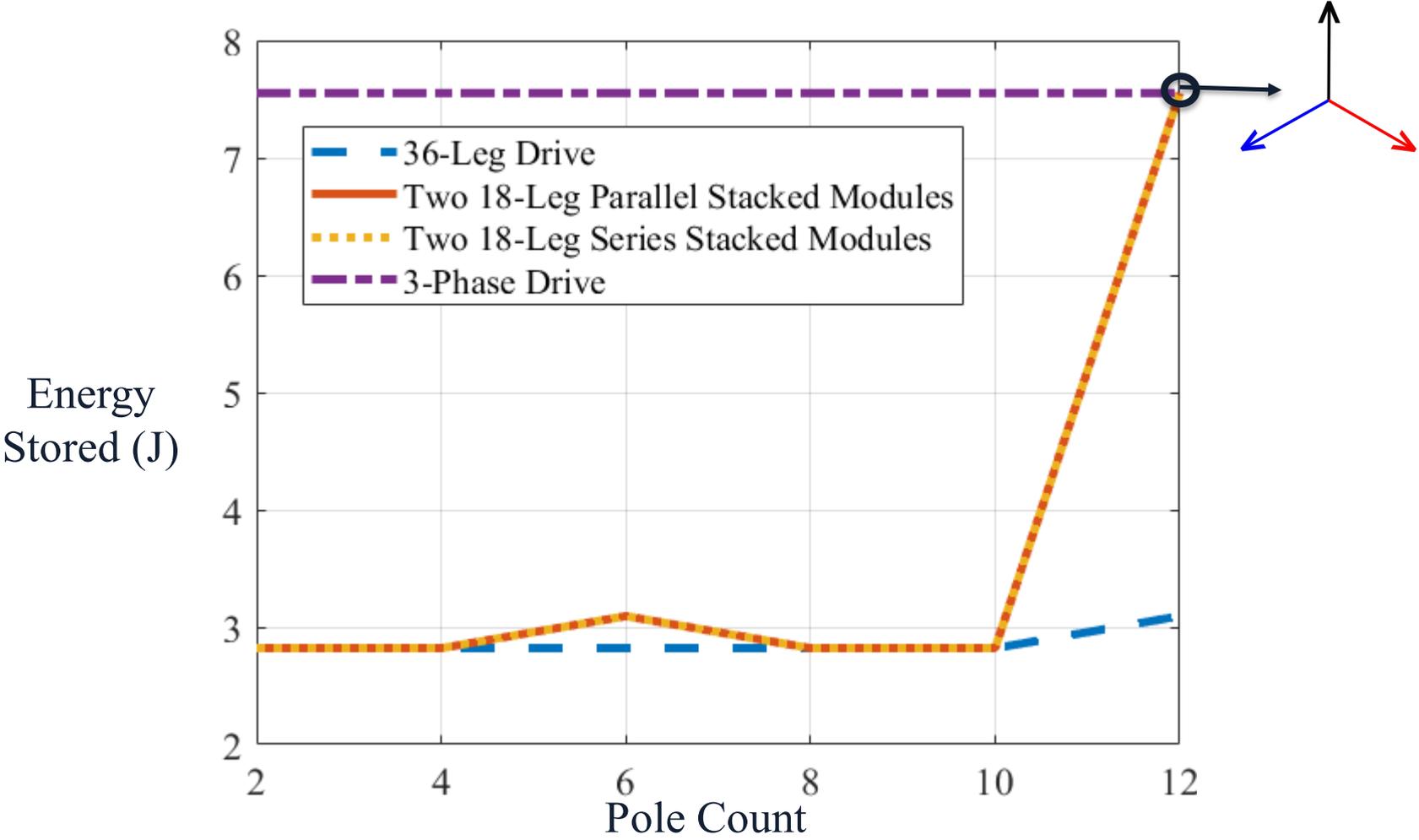
# 3-phase operation constrains capacitor sizing irrespective of the number of inverter legs



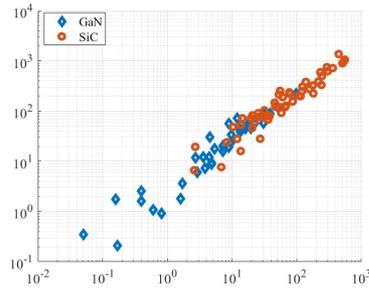
# Dividing the drives into modules affect the capacitance value



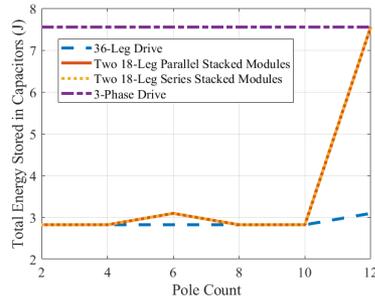
# From an energy storage perspective, series and parallel combination of modules are identical



# Outline



## Effect of Drive Architecture on Inverter Losses

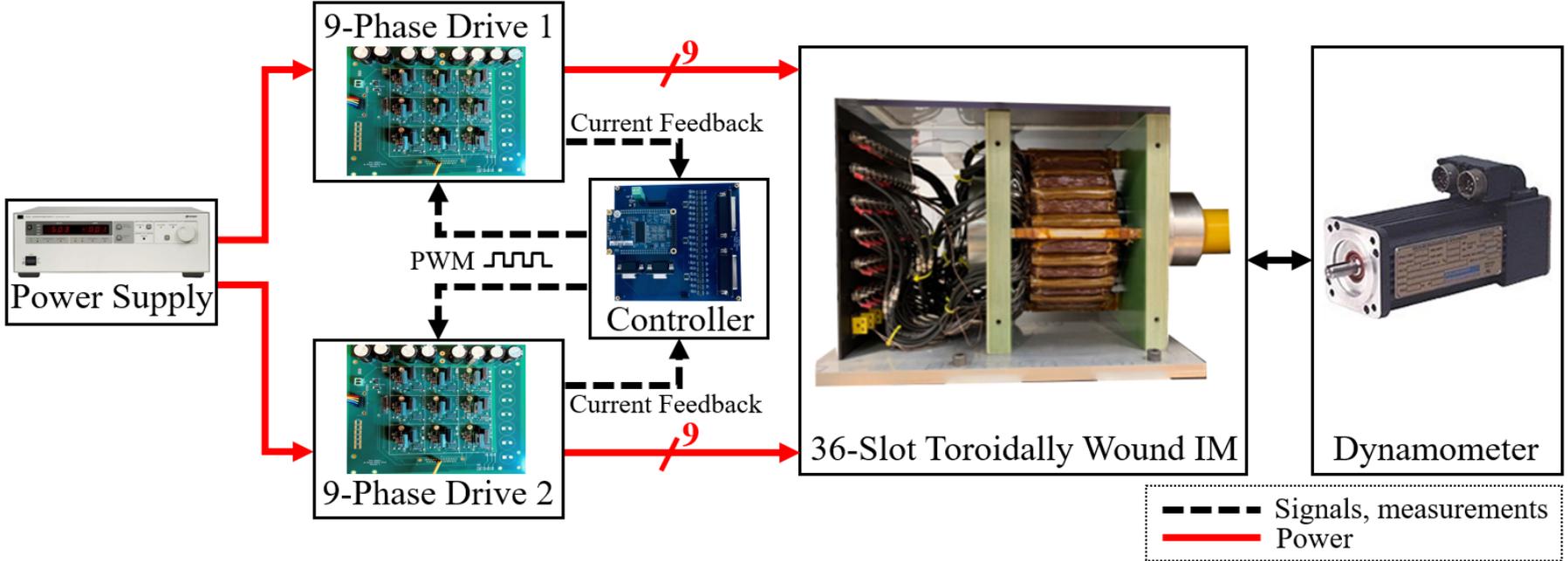


## Filter Capacitor Sizing

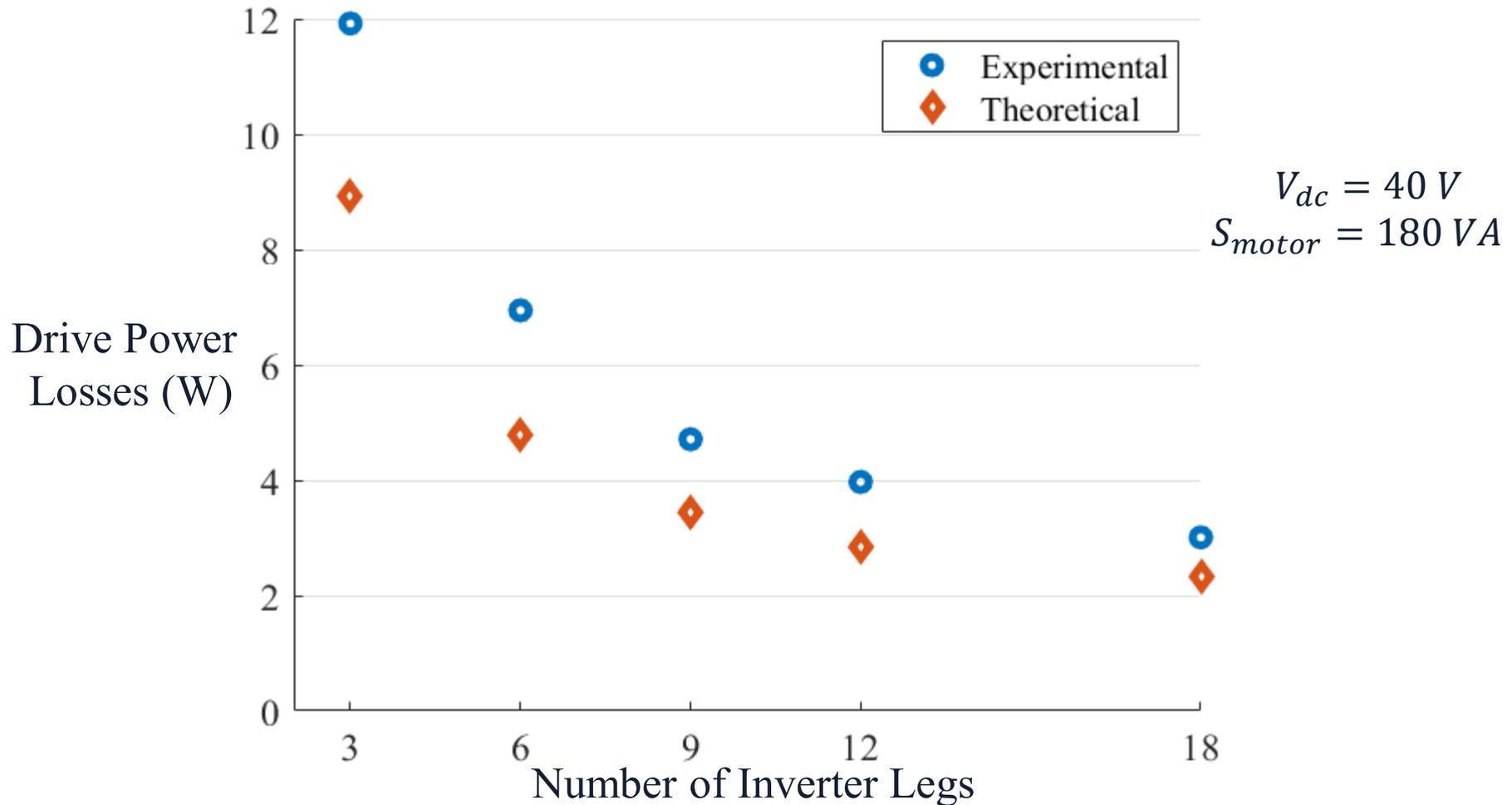


## Experimental Results

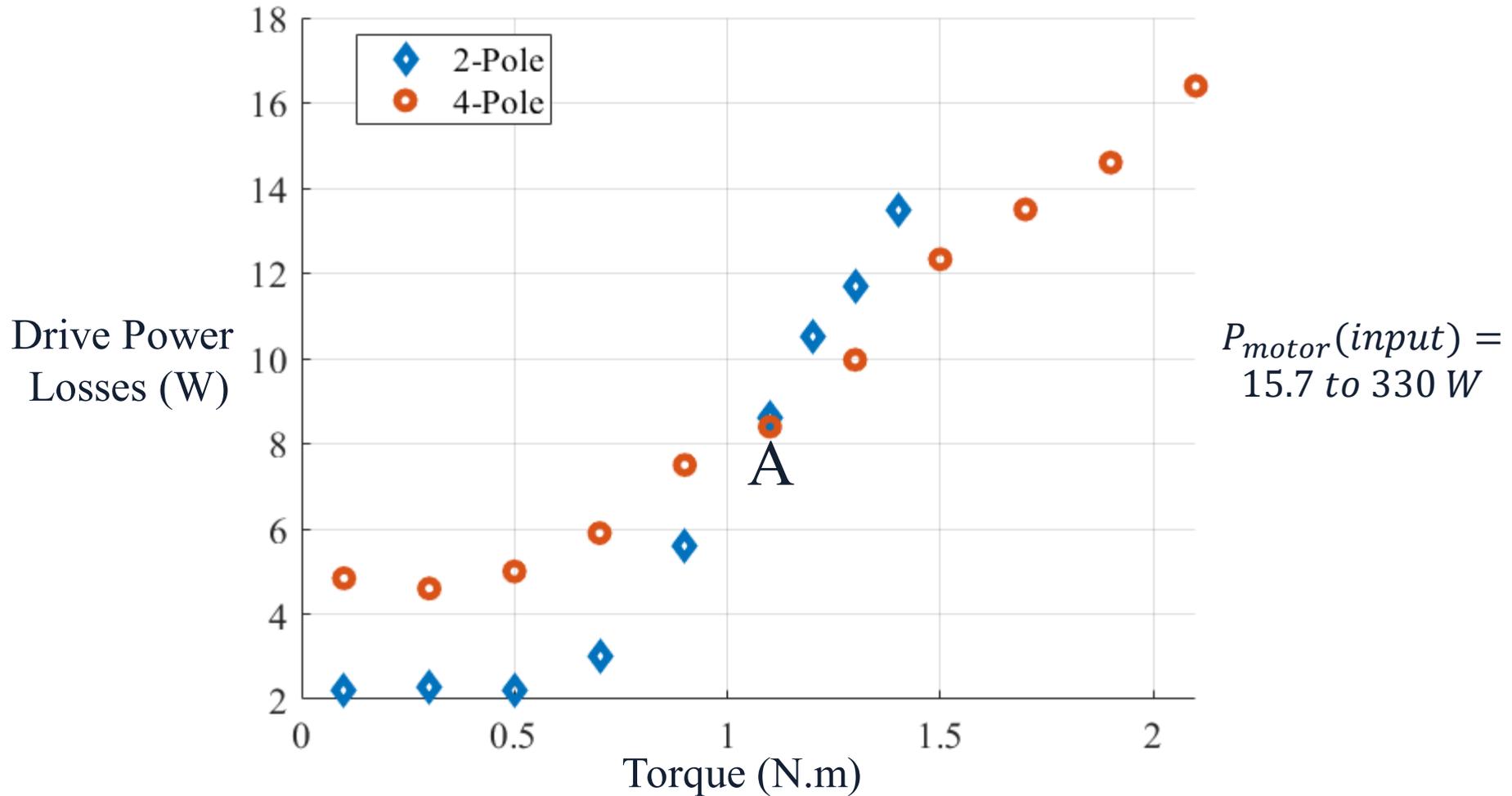
# Experimental Setup. The 18-leg drive is modularized into two 9-leg GaN-based modules



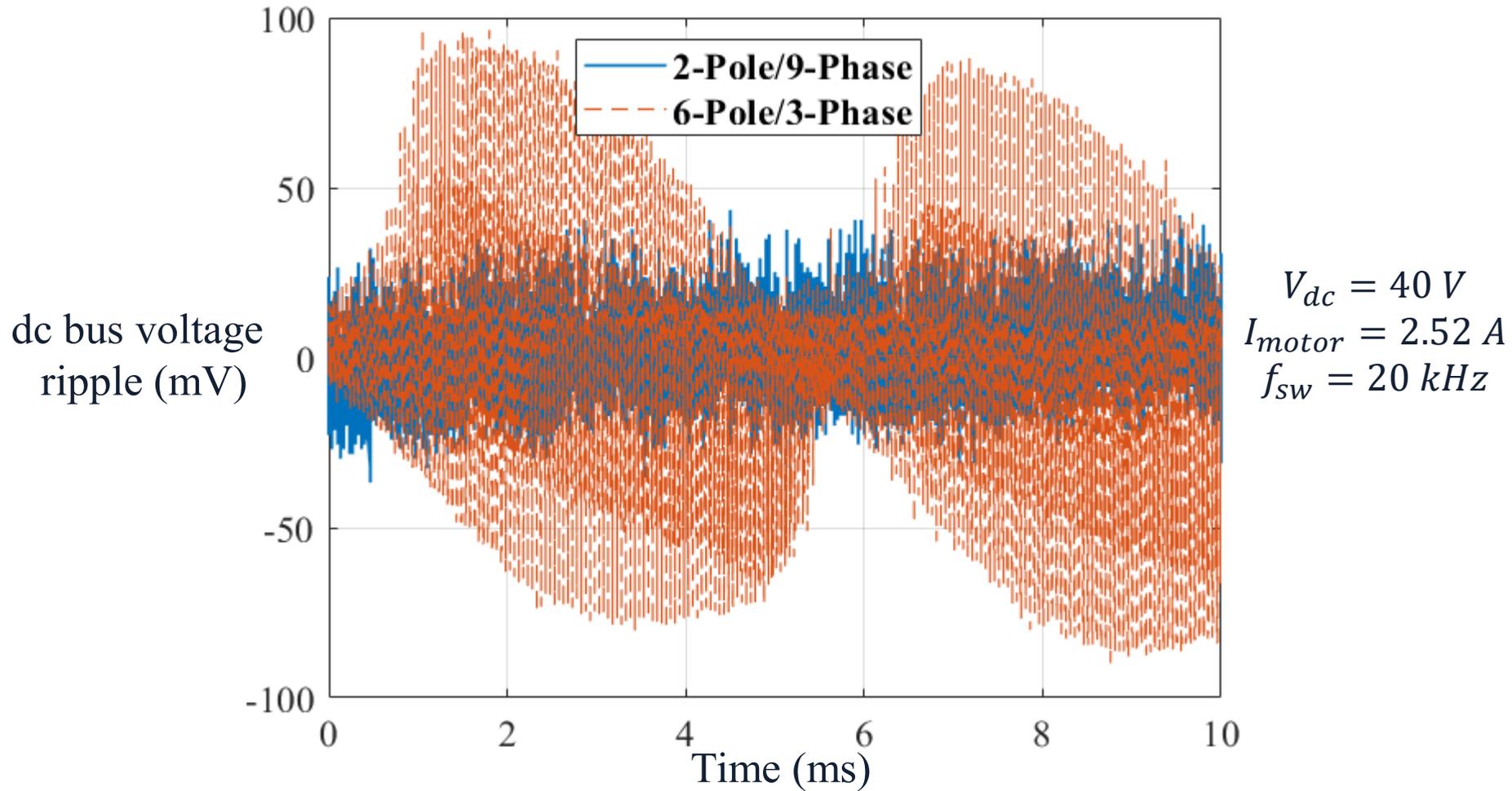
# Power Loss (W) decreases as the number of inverter legs used increases



# Varying the machine pole count adds a degree of freedom to minimize drive losses



# dc Bus voltage ripple is higher when a 3-phase excitation is done



# Key takeaways

- 1) A higher number of inverter legs provides more flexibility to change pole count of an IM
- 2) With higher number of inverter legs, more efficient drives can be designed by using lower rated devices
- 3) The pole count extends the machine speed range and adds a degree of freedom to maximize drivetrain efficiency

# Acknowledgment

- Grainger Center for Electric Machinery and Electromechanics at the University of Illinois
- The Power Optimization of Electro-Thermal Systems (POETS) NSF Engineering Research Center at the University of Illinois
- Dr. Matthew P. Magill

Thank You



# Questions

