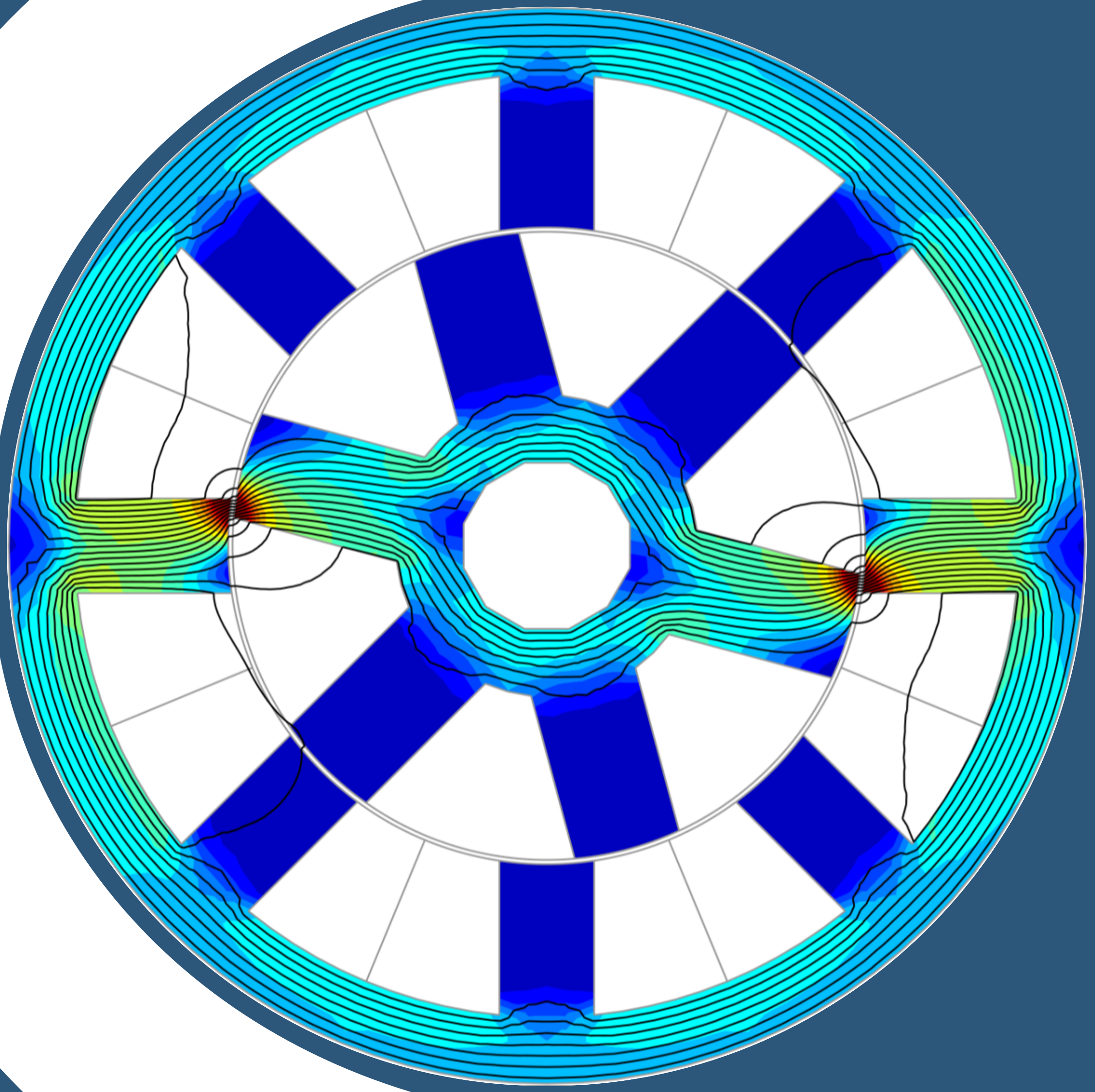
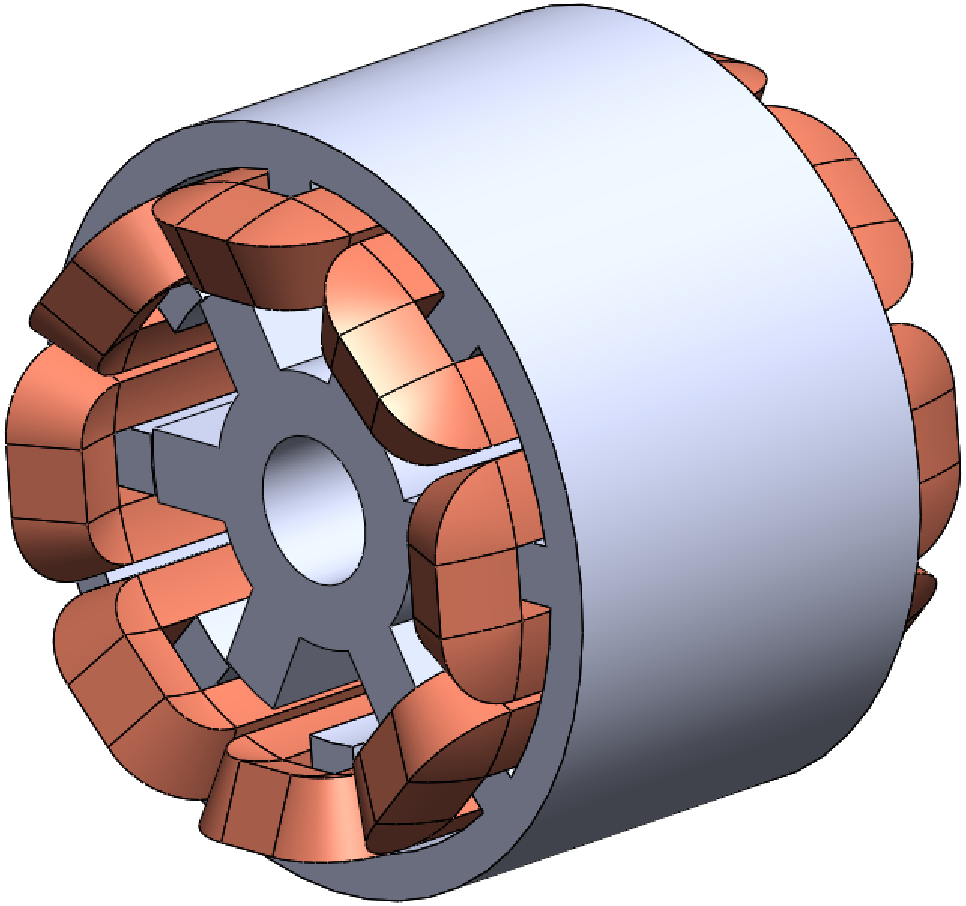


A SYSTEM-ORIENTED APPROACH FOR OPTIMAL DESIGN OF SWITCHED RELUCTANCE MOTORS USING EMDLAB

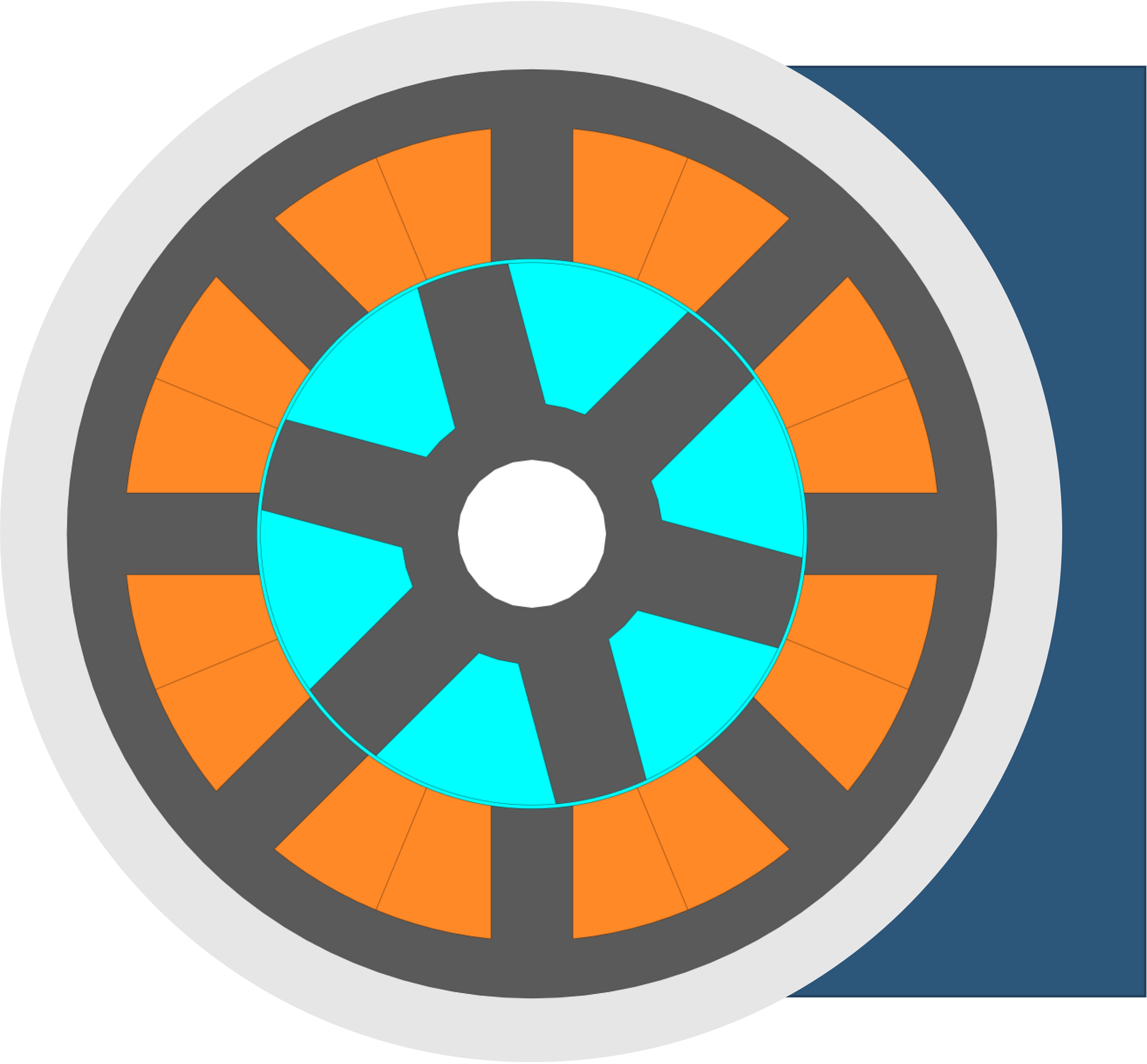
WHY SRM?

Switched reluctance motors (SRMs) continue to attract attention due to their simple construction, fault tolerance, and high-speed capability. Designing high-performance SRMs, however, requires an integrated approach that accounts not only for the electromagnetic structure but also the converter and control system.



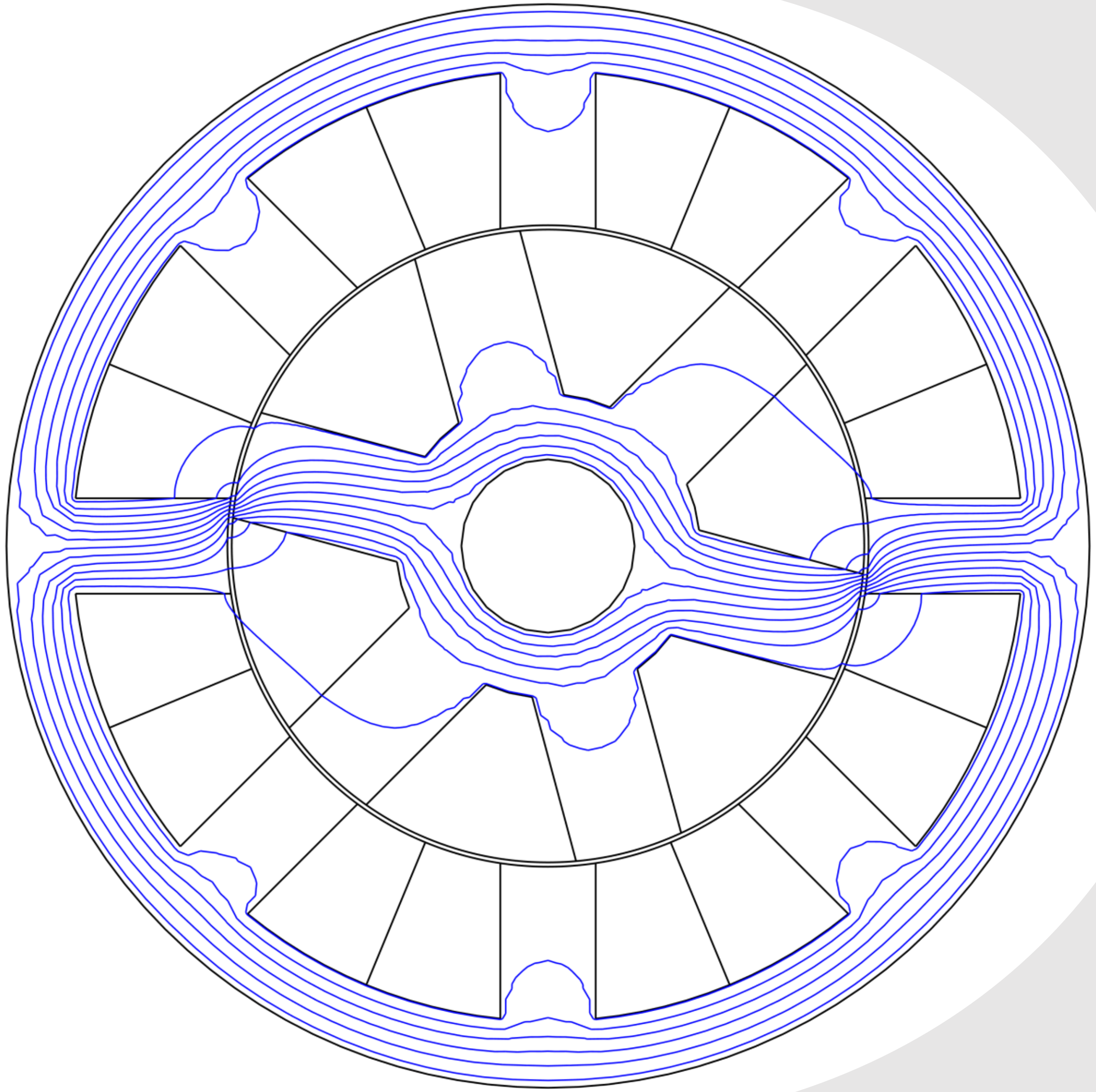
MOTOR SIZING

- **Initial Sizing Using Analytic Equations:** Determine preliminary dimensions (stator/rotor diameter, stack length, number of turns) based on required torque, speed, and power.
- **Material Selection:** Choose suitable core and conductor materials to optimize magnetic performance, thermal limits, and efficiency.
- **Pole Combination Selection:** Decide on the optimal number of rotor and stator poles to balance average torque, torque ripple, and manufacturability.
- **Inductance Calculation:** Compute phase inductances in aligned and unaligned rotor positions to evaluate magnetic performance.
- **Average Torque Calculation:** Estimate average torque from the flux-linkage and current profiles to verify that the design meets performance targets.

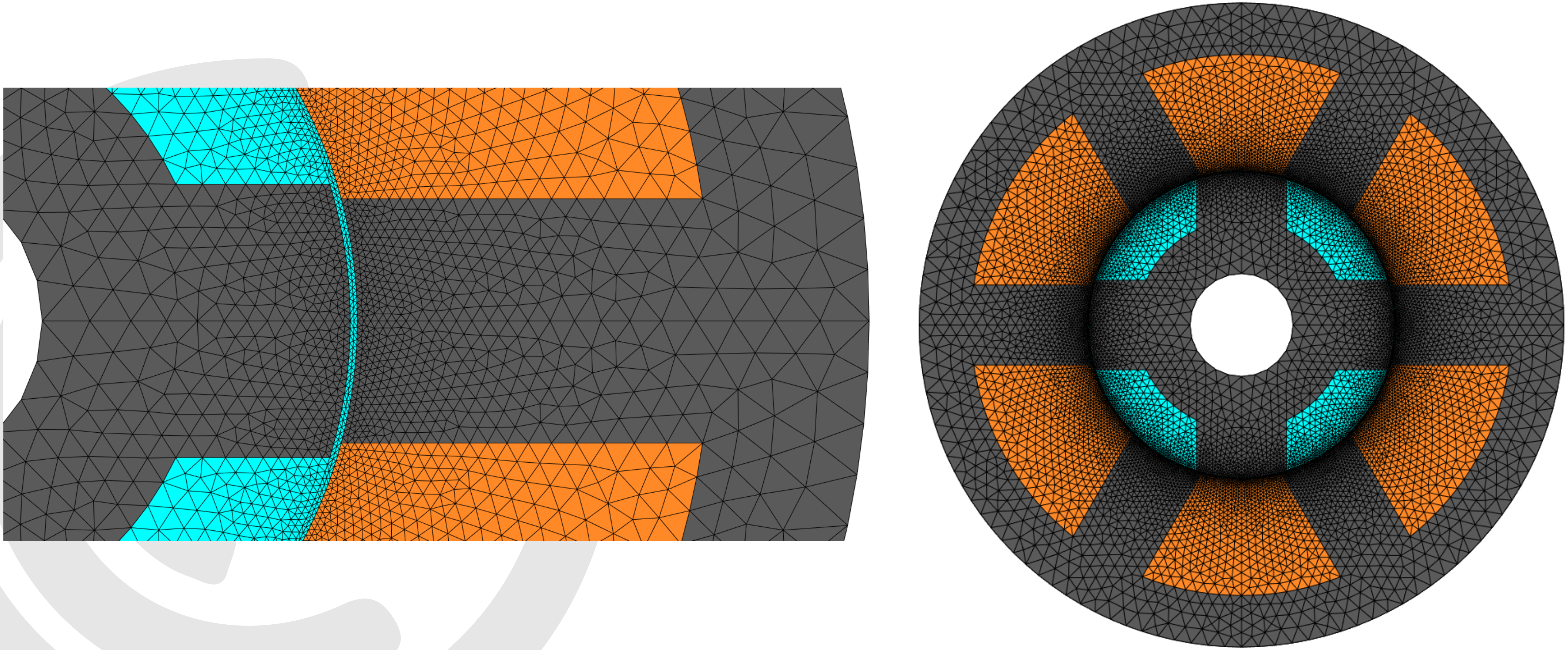


SIMULATION AND ANALYSIS: MAGNETO-STATIC ANALYSIS

- Performing 2D nonlinear FEM simulations of the motor using **EMDLAB**.
- **Calculation of static torque curve**: Torque vs. rotor position for different excitation levels.
- **Flux linkage characteristic**: Phase flux linkage profiles vs. excitation level for different rotor positions.
- **Inductance calculation**: Phase inductance determined for aligned and unaligned positions to evaluate the saliency ratio.

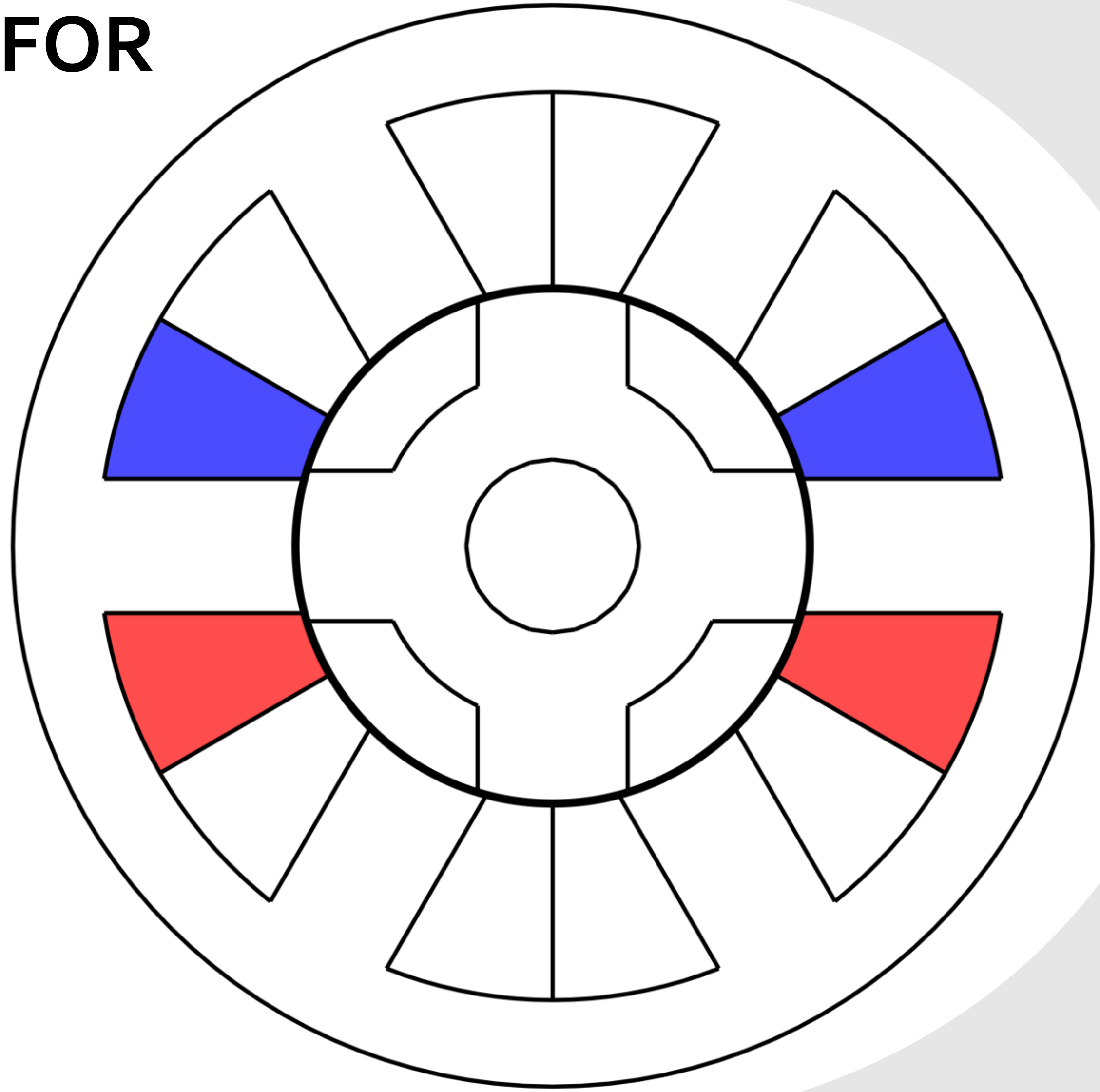


HIGH QUALITY MESH GENERATION IN EMDLAB



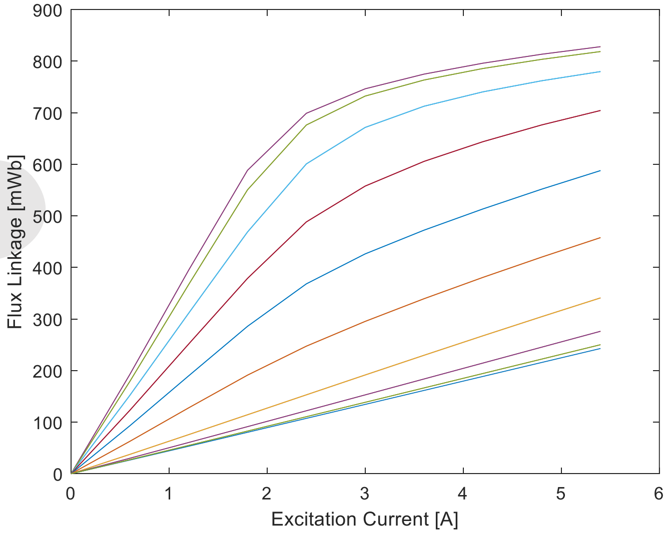
SIMULATION AND ANALYSIS: EQUIVALENT MOTOR MODEL FOR FAST SIMULATION

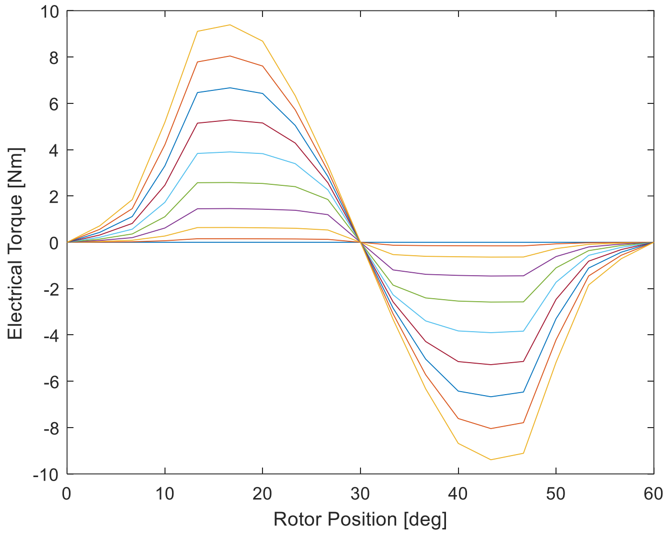
- Generated a reduced-order equivalent model of the motor using parallel finite element computations.
- Enabled rapid dynamic simulations while retaining accuracy of torque and flux profiles.
- Conducted **fast dynamic simulations** using two Simulink models:
- **Simulink model #1: neglecting the effect of mutual inductances (simpler)**
- **Simulink model #2: including the effect of mutual inductances**



DATA DERIVED BY PARALLEL FINITE ELEMENT CALCULATIONS IN EMDLAB

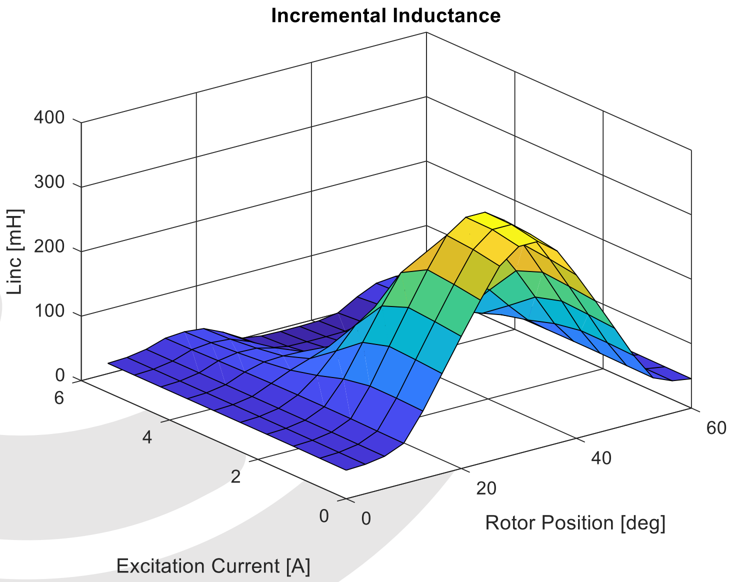
$$\lambda(i,\theta_r)$$

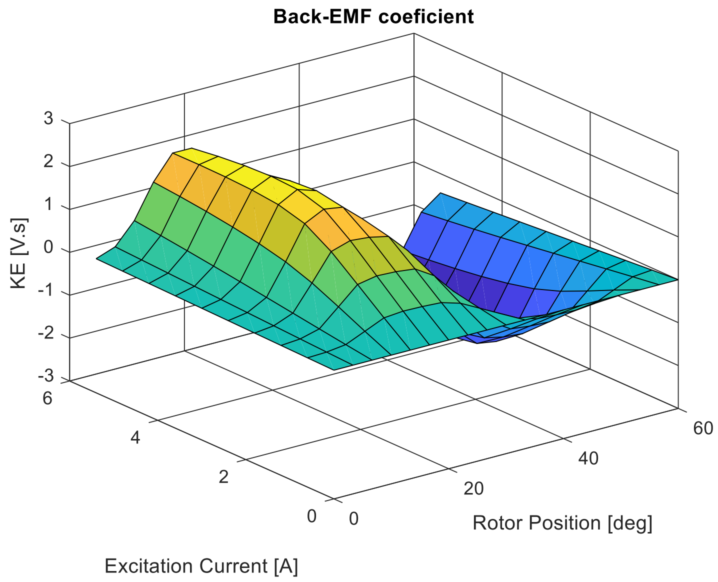




$$T_e(i,\theta_r)$$

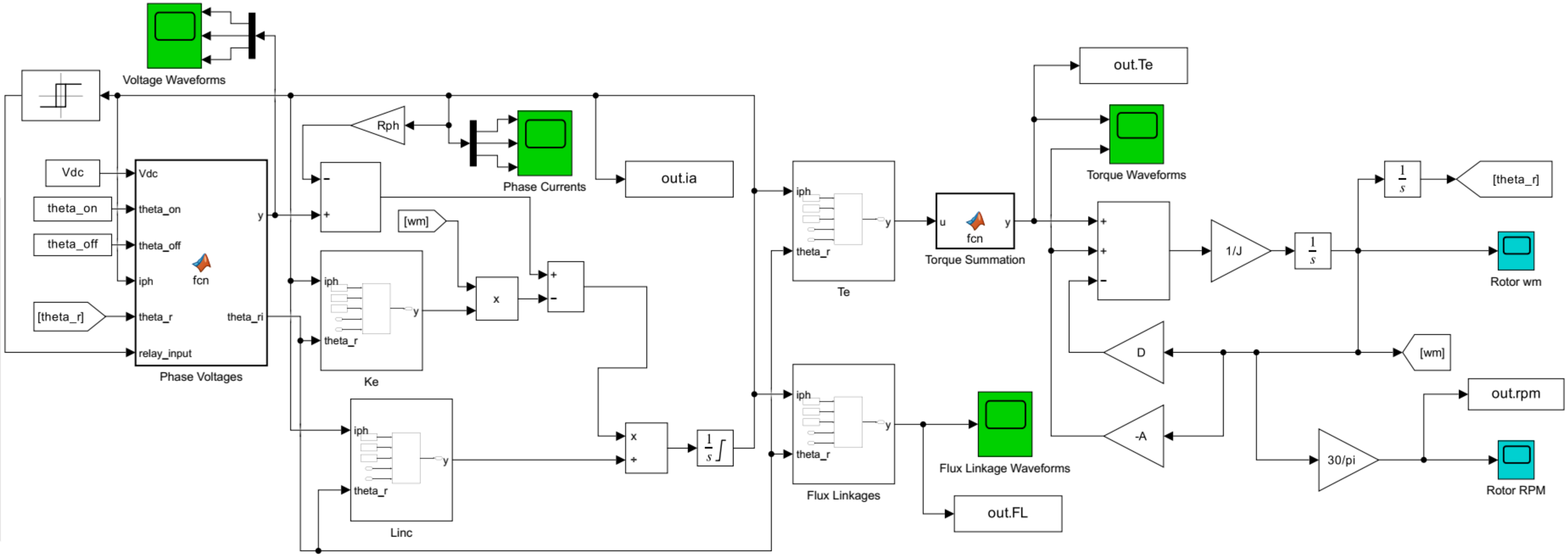
$$L_{inc} = \frac{\partial \lambda}{\partial i}$$



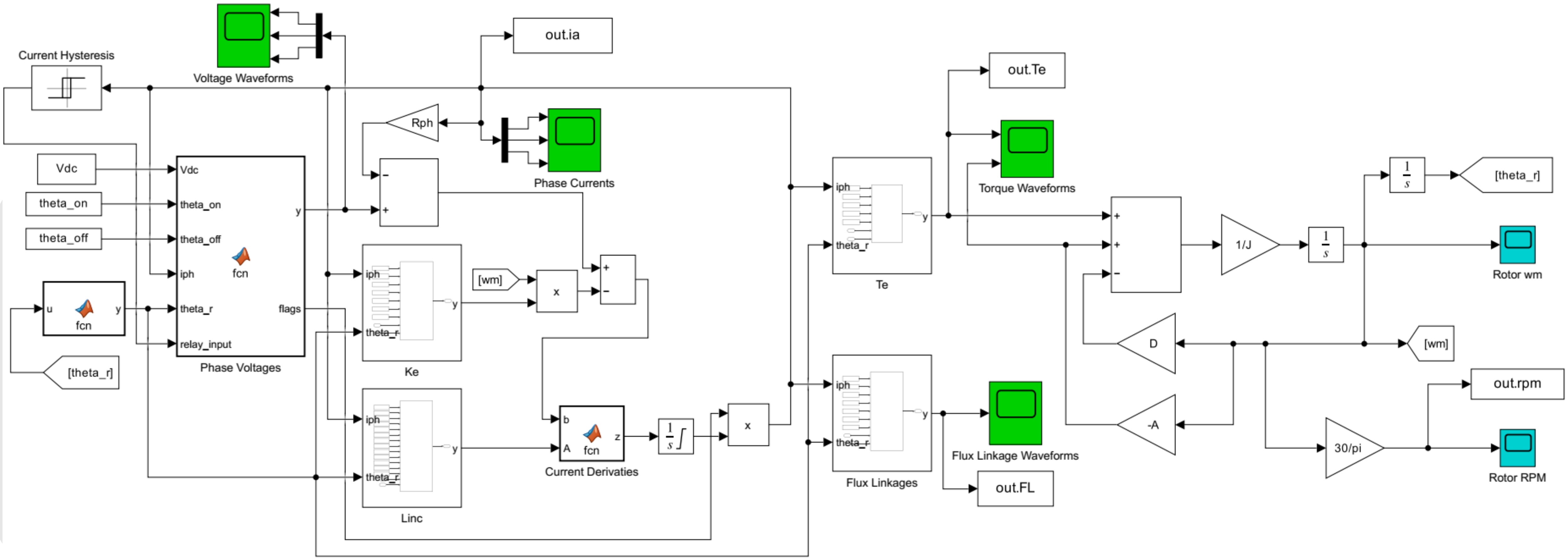


$$K_E = \frac{\partial \lambda}{\partial \theta_r}$$

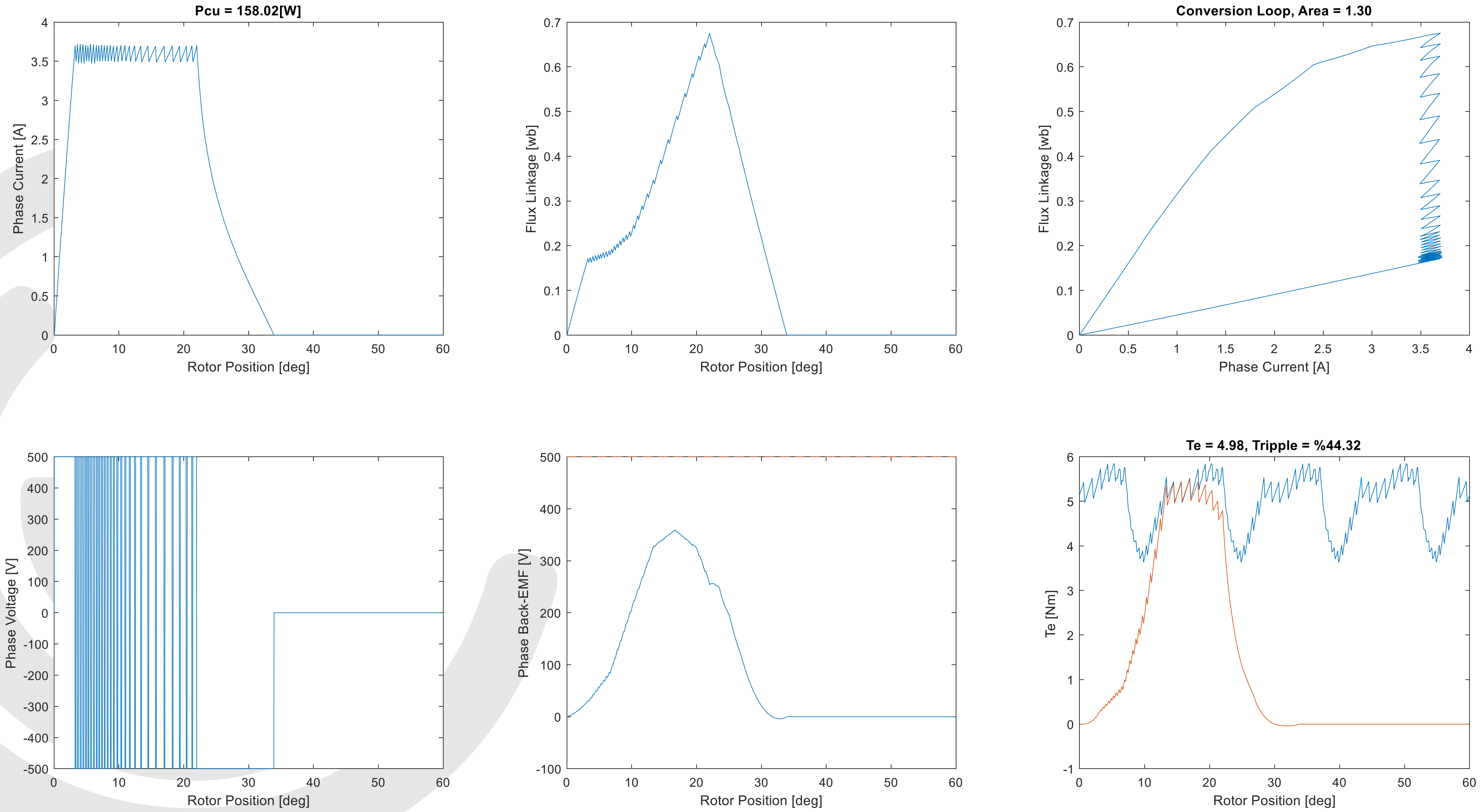
SIMULINK MODEL #1: NEGLECTING MUTUAL INDUCTANCES



SIMULINK MODEL #2: INCLUDING MUTUAL INDUCTANCES

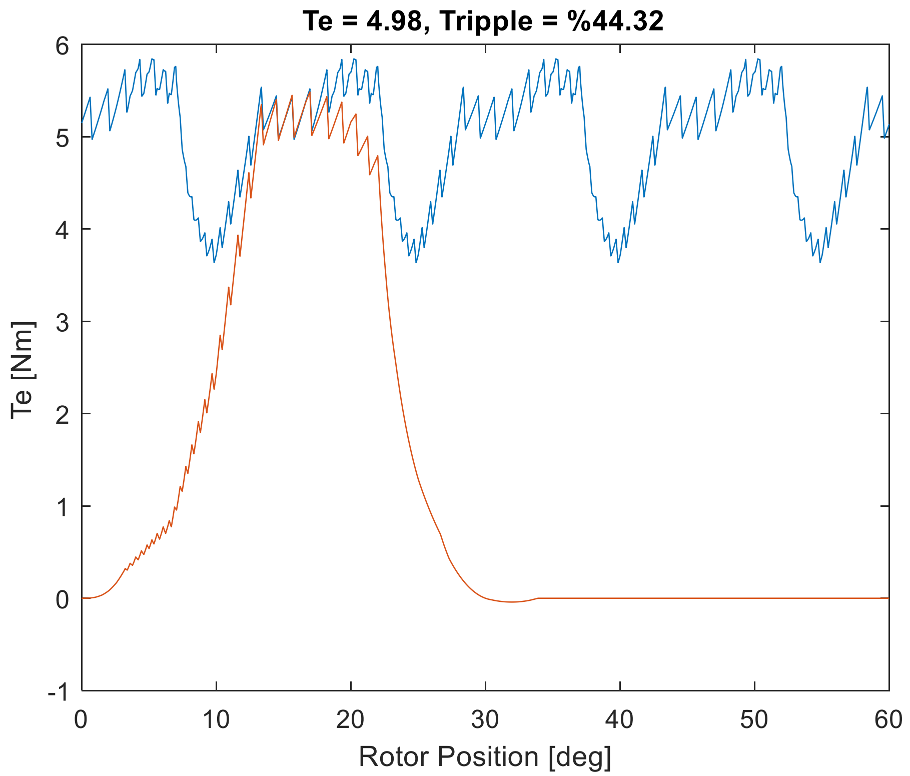


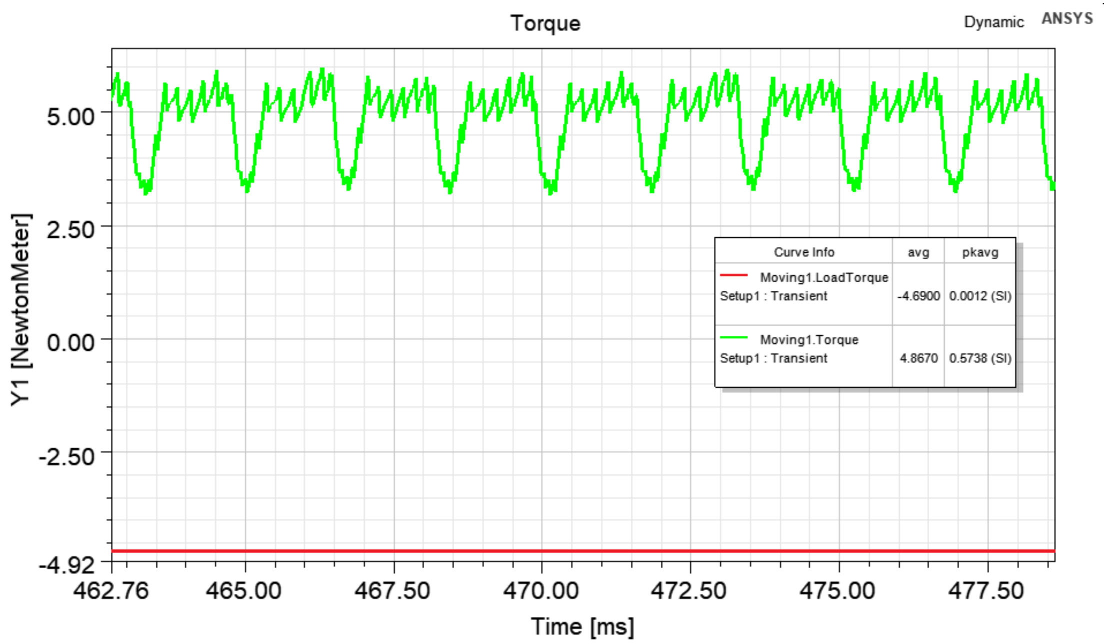
RESULTS OF SIMULINK MODELS AT STEADY STATE



TORQUE PROFILE COMPARISON

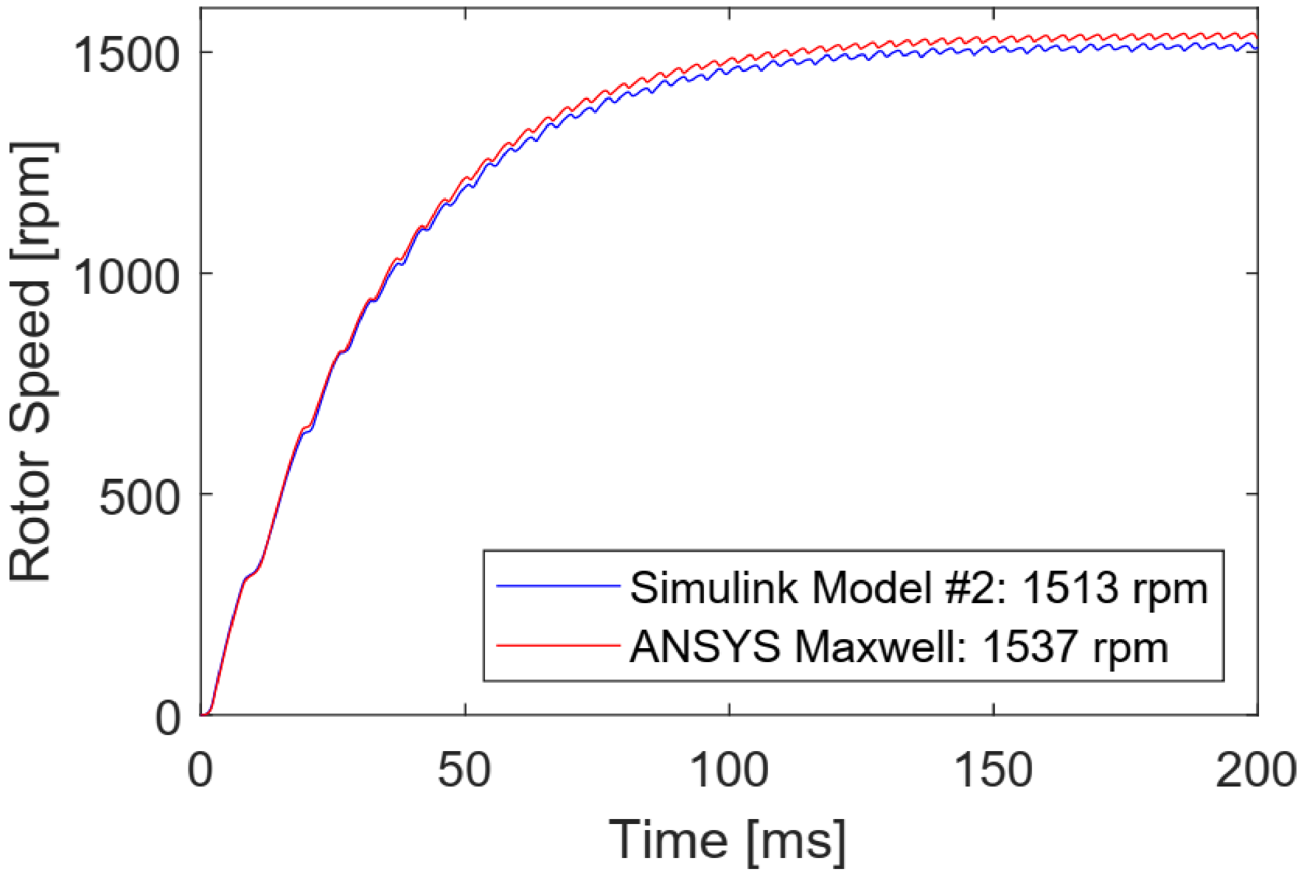
DEVELOPED SIMULINK MODEL

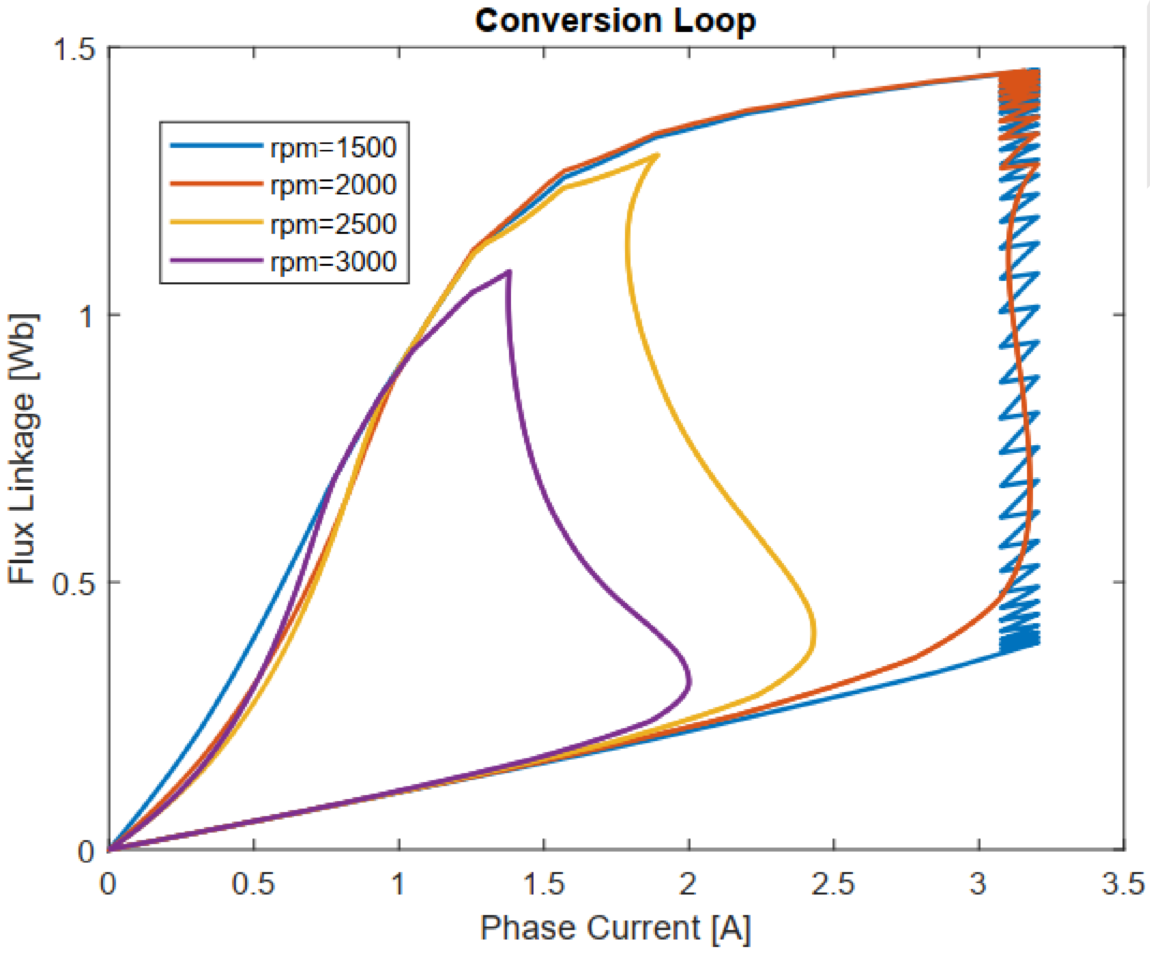




VOLTAGE FED SIMULATION IN ANSYS

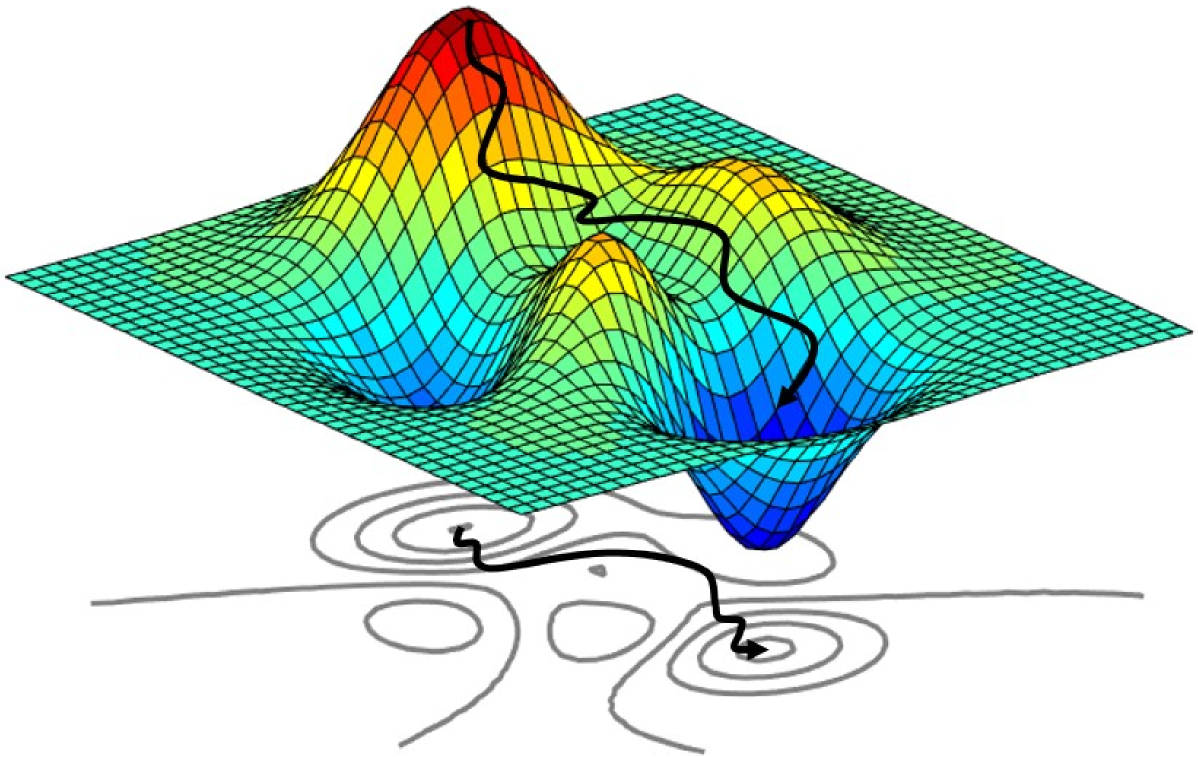
CONVERSION LOOPS DURING TRANSIENT OPERATION





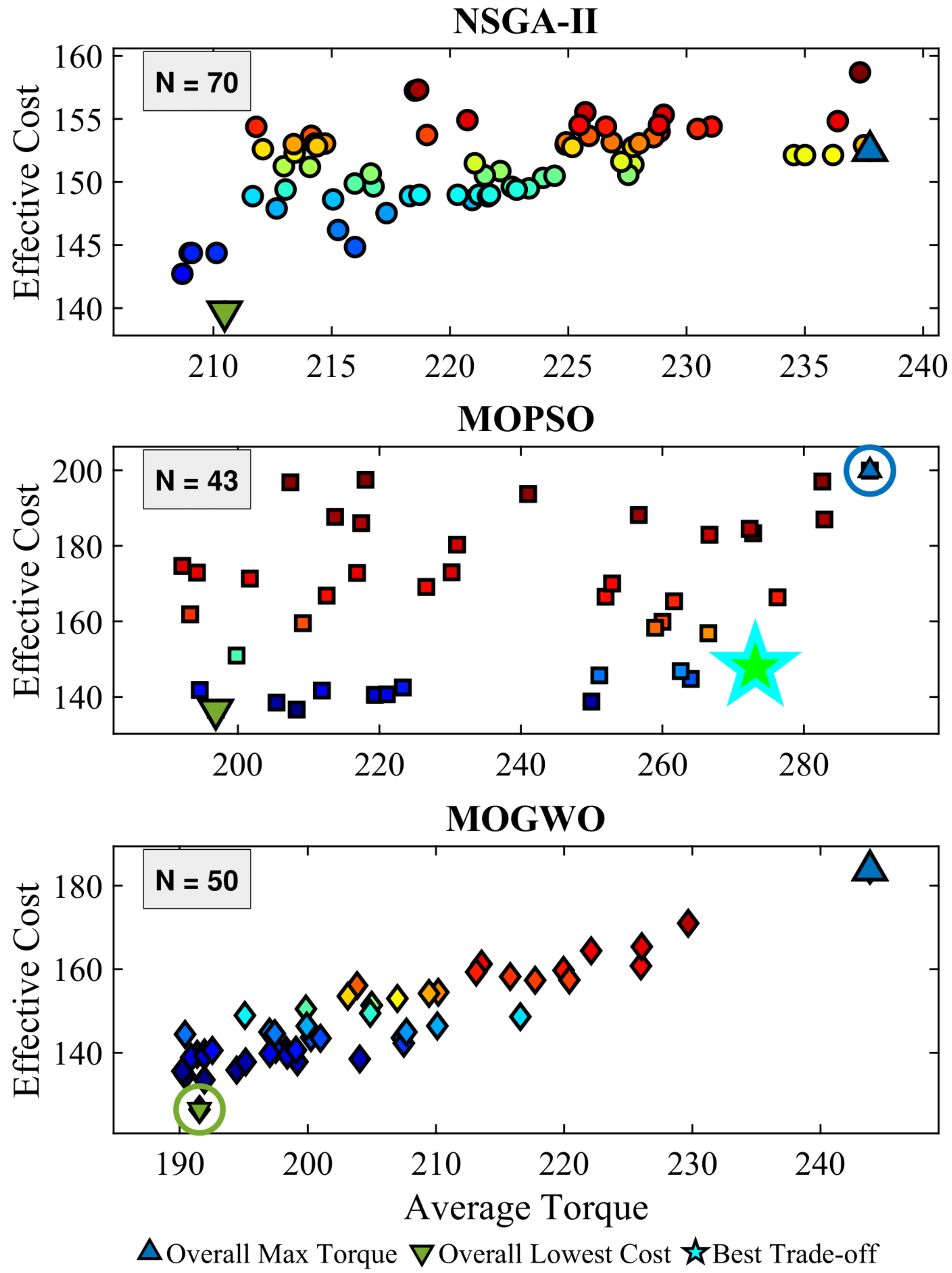
OPTIMIZATION

- **System-Oriented Approach:** Optimizing the motor in isolation is insufficient. The focus is on the **entire motor & drive system**, including the SRM, and the control strategy, as they are all deeply interconnected.
- Optimization relies on accurate and efficient models. EMDLAB provides a significant advantage by enabling the generation of **high-fidelity motors models** through parallel finite element calculations.
- **Surrogate Modeling:** Using techniques like response surfaces or neural networks to create a fast "metamodel" based on FEA data, enabling rapid exploration of the design space.



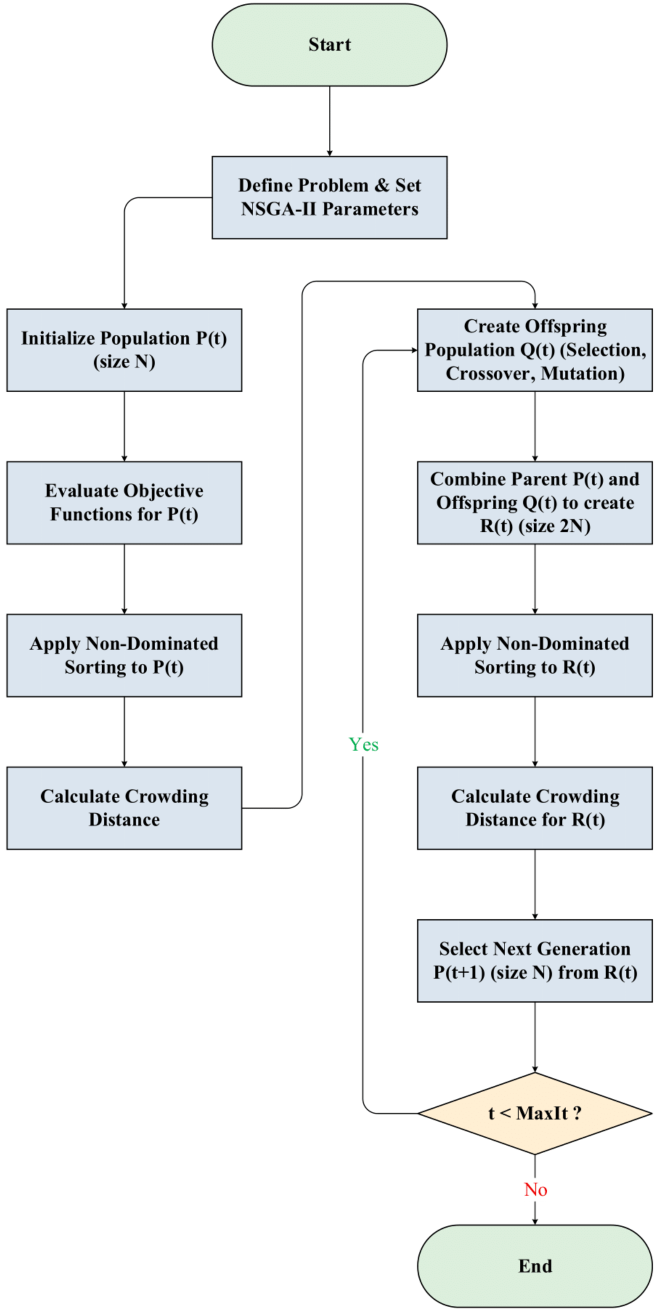
OPTIMIZATION OBJECTIVES

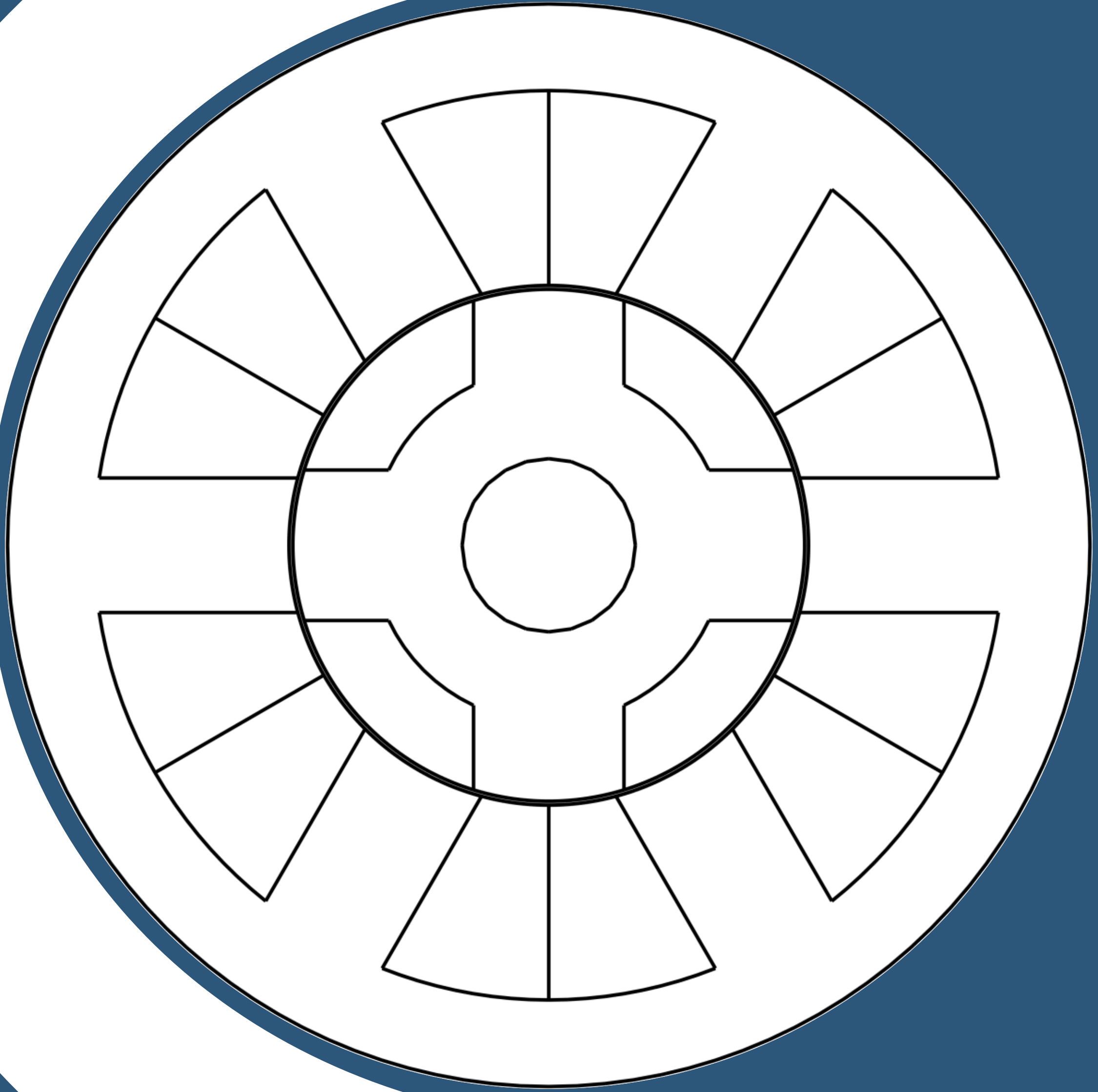
- **Performance Maximization:**
  - Maximize **average torque**
  - Maximize **power density** (power per unit volume/mass)
  - Maximize **efficiency** across a specific drive cycle
- **Performance Quality:**
  - Minimize **torque ripple**, which is a primary challenge in SRMs and a key driver for "system-oriented" (co-design) optimization with control.
  - Minimize **acoustic noise** and vibration.
- **Cost & Resource Minimization:**
  - Minimize **total manufacturing cost**.
  - Minimize **material usage** (e.g., volume of electrical steel and copper).
  - Minimize **total mass or volume**.
- **Operational Robustness:**
  - Minimize **thermal rise** in the windings and core.
  - Maximize the **constant-power speed range**.



OPTIMIZATION METHODOLOGIES

- **Single-Objective Optimization (SOO):**
  - Focuses on a single goal (e.g., *only* maximizing efficiency).
  - Useful for simpler problems or for understanding the limits of a single parameter.
  - Algorithms include: Gradient-based methods, classical Genetic Algorithms (GAs), Particle Swarm Optimization (PSO).
- **Multi-Objective Optimization (MOO):**
  - The most common real-world scenario, handling **conflicting objectives** (e.g., maximizing torque often increases cost and mass; minimizing torque ripple might reduce average torque).
  - The goal is not a single "best" solution but the **Pareto-optimal front**: a set of non-dominated solutions that represent the best possible trade-offs. The user can then select the solution that best fits their needs from this front.
  - Common algorithms include:
    - **NSGA-II** (Non-dominated Sorting Genetic Algorithm II)
    - **MOPSO** (Multi-Objective Particle Swarm Optimization)
    - **MOGWO** (Multi-Objective Grey Wolf Optimizer)
    - **SPEA2** (Strength Pareto Evolutionary Algorithm 2)
    - **MODE** (Multi-Objective Differential Evolution)





THANK YOU!

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https://github.com/emdlab-package/emdlab-win64