

# **Rapid multi-physics approach to the development of electric drive systems for hybrid and electric vehicles**

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Advanced Technology Group  
Electric Power Systems**

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# Presentation Outline

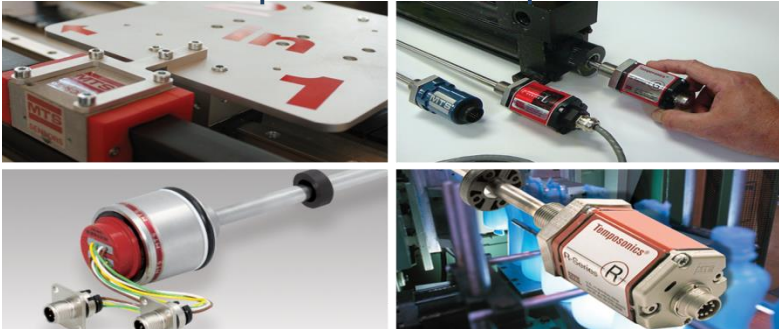
- MTS Systems Corporation
- Electric Power Systems
- Development Cycle for Motors and Drive
- Applications

# MTS Products, Systems and Services

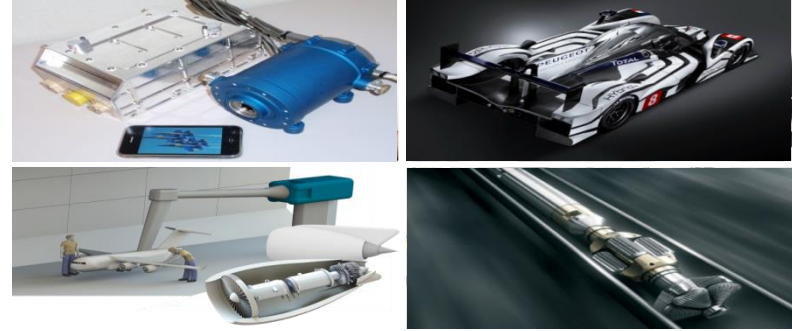
## Test Vehicles, Materials and Structures



## Sensors Liquid level and position



## Electric Power Systems Vehicles, Industrial



## Services Consulting, Monitoring, Repair



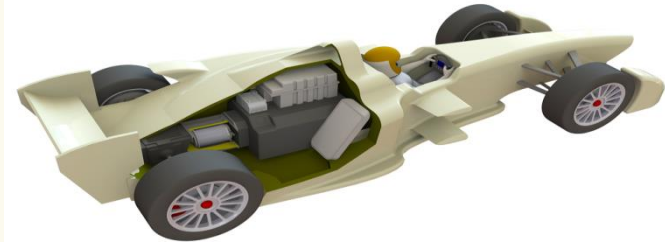
# EPS – Electric Power Systems

Develop and manufacture high performance electric motors and controls.

## PORTFOLIO

- » Traction motors
- » ERS
- » Dynos
- » Industrial solutions
- » Power generation
- » Oil and gas exploration
- » Aerospace applications

### Formula E drive System



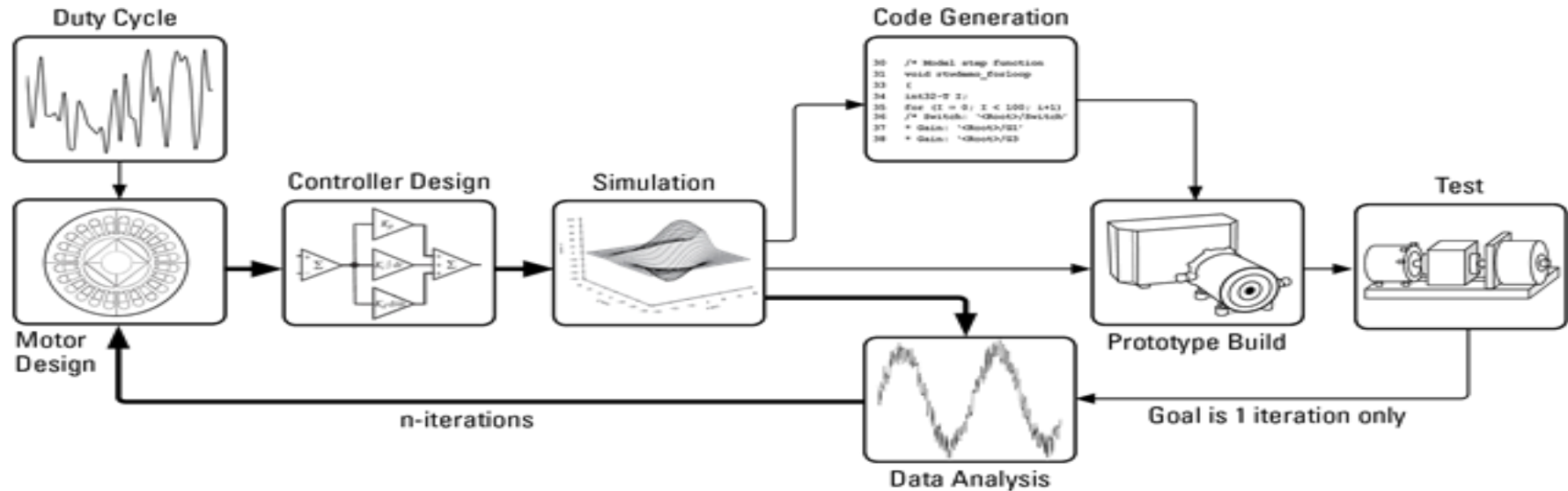
- » Traction drive
- » Kinetic energy recovery

### Formula 1 Energy Recovery System

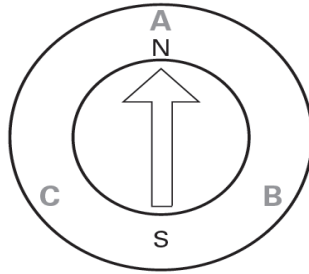


- » Kinetic energy recovery
- » Heat energy recovery

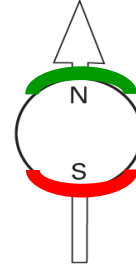
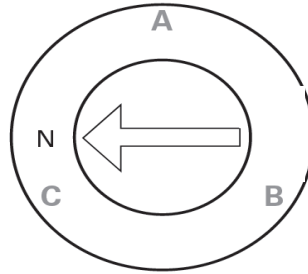
# Development Cycle for Motors and Drives



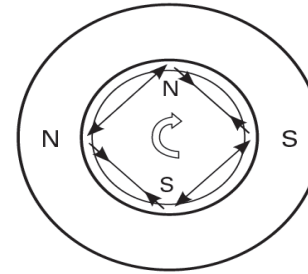
# Motor Principle



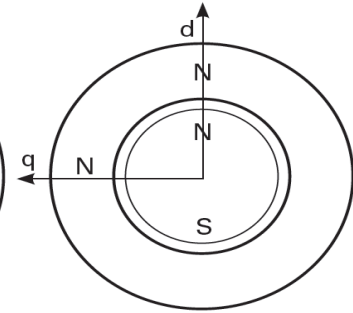
Stator



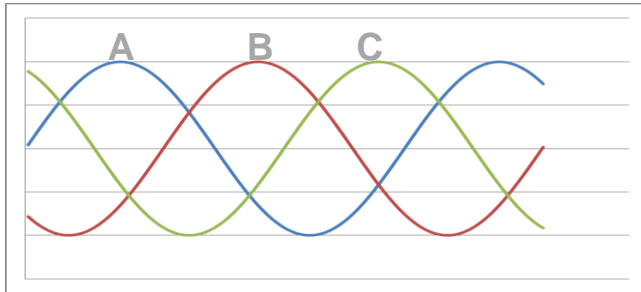
Rotor



Torque  
Rotation

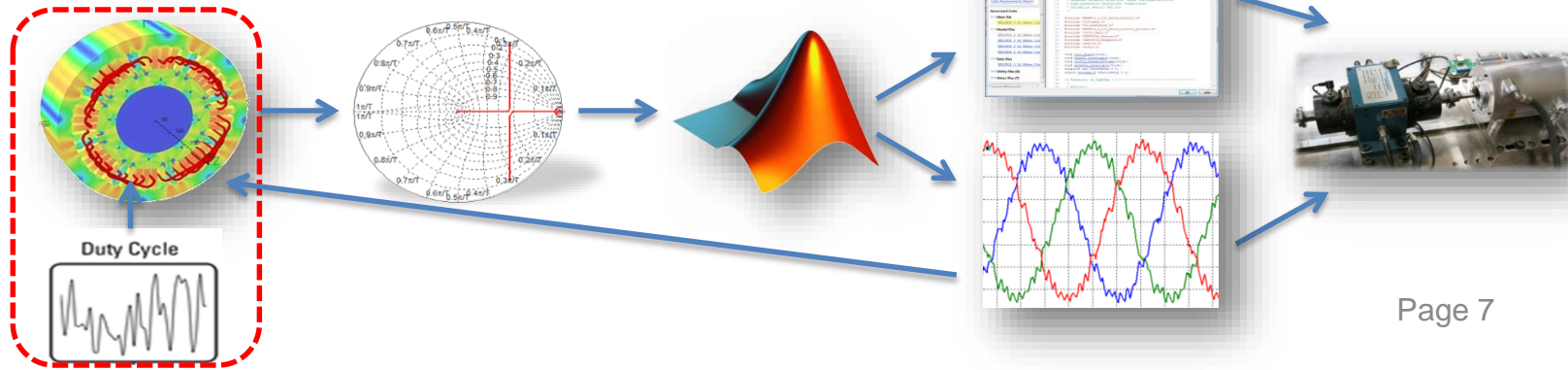


Control  
 $I_q = \text{torque}$   
 $I_d = \text{"correction"}$



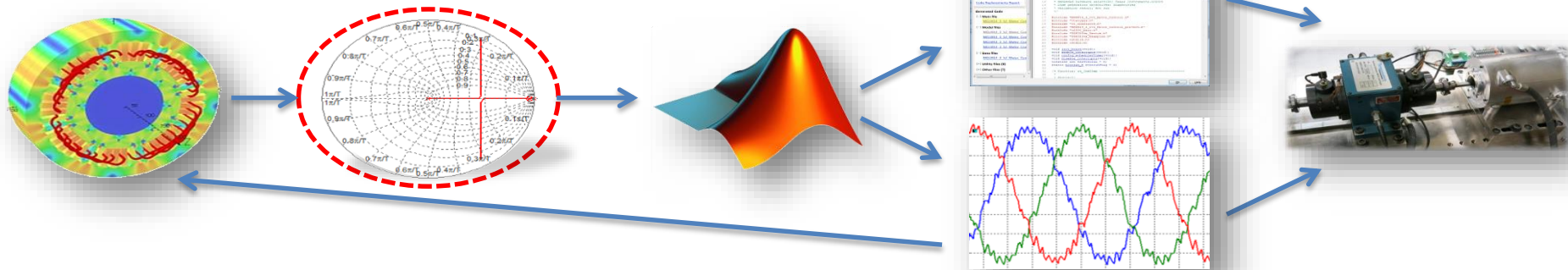
# Motor/Drive System Design Process

- Duty Cycle drives base design, topology, etc.
- FEA of EM design
- Control Design
- Simulation
- Data Analysis/Hardware Design
- Code Generation
- Testing & Verification



# Motor/Drive Design Process

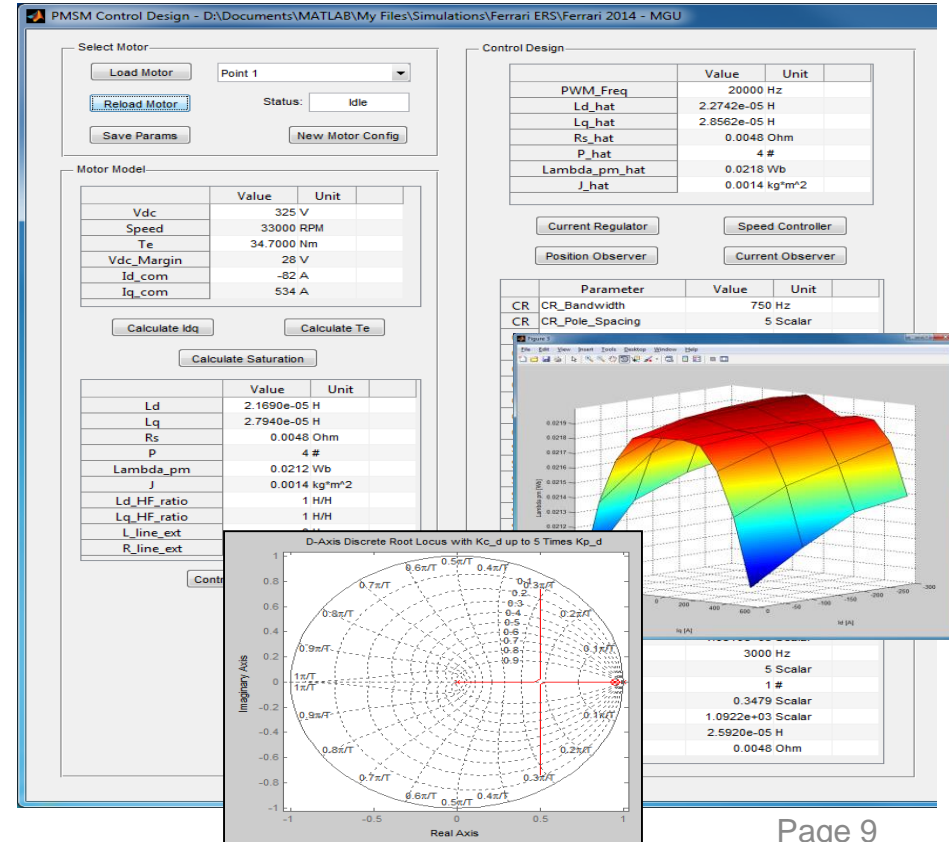
- FEA
- **Control Design**
- Simulation
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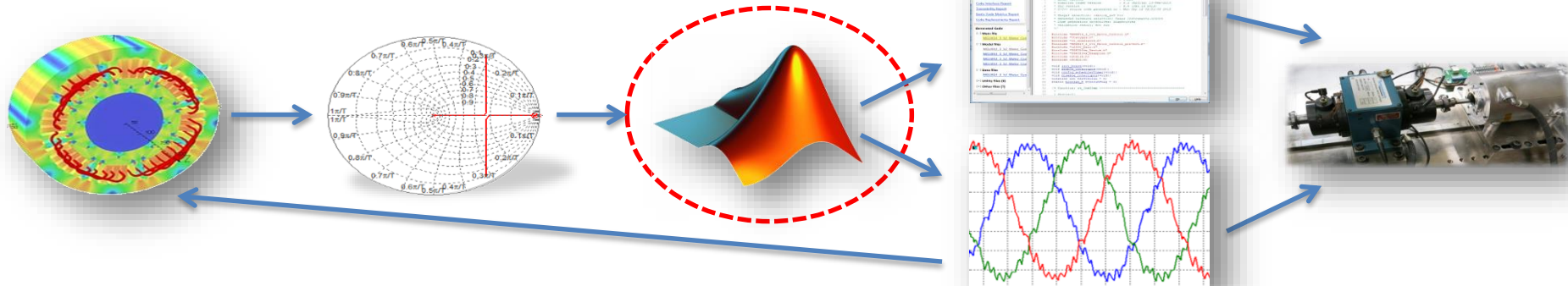
# Control Design

- Motor parameters lookup table
  - Generated with FEA
  - $L_d$ ,  $L_q$ , and  $\lambda$  vs  $I_d$  and  $I_q$
- Discrete control design
  - d-q current commands
  - Speed command
  - Speed observer
  - Current observer (Self Sensing)
- Operating point calculations
  - Including saturation
  - MTPA and Field Weakening
- Rapid and robust control design



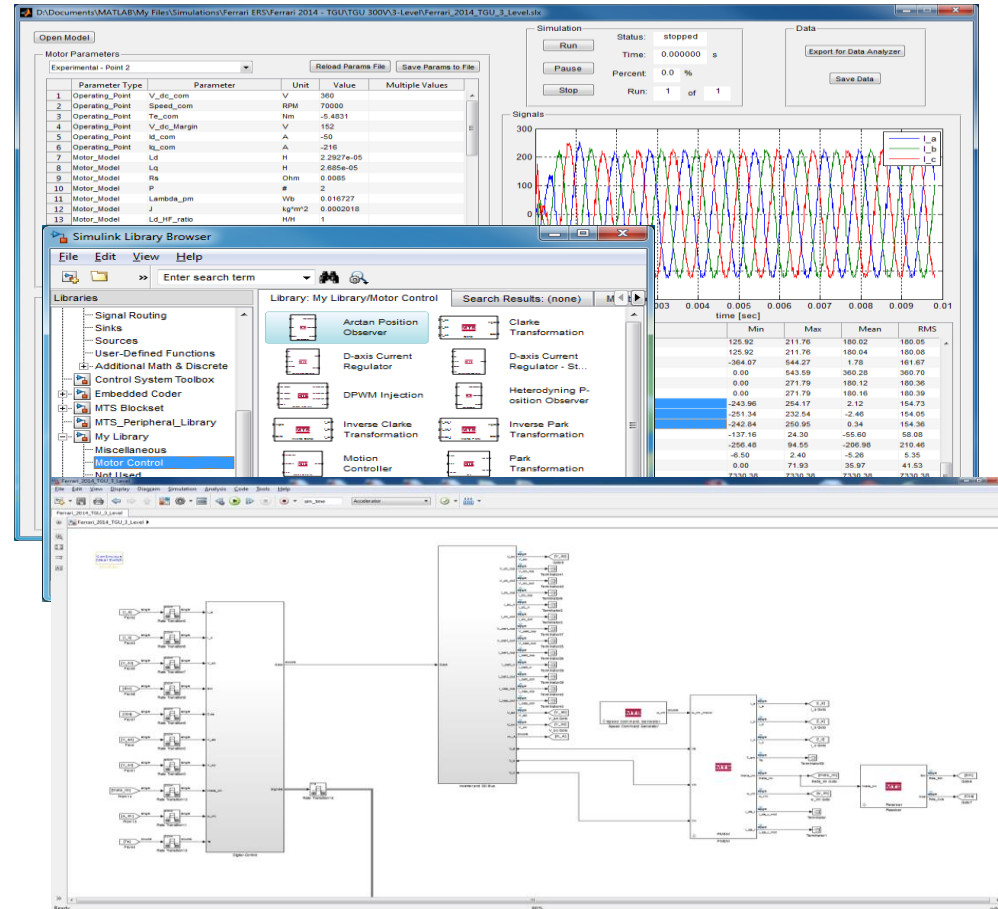
# Motor/Drive Design Process

- FEA
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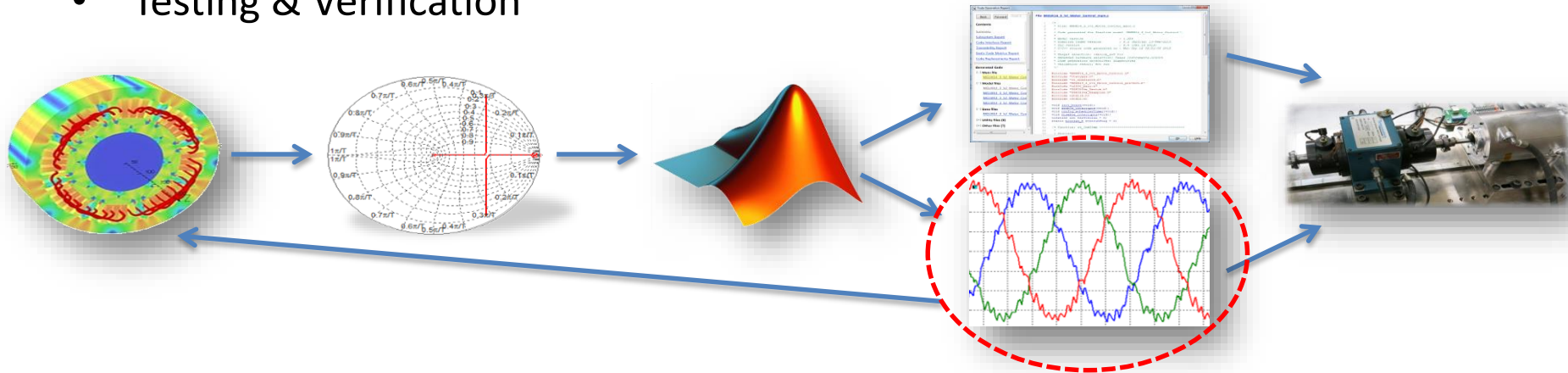
# Simulation

- Parameters imported from motor control design
- Quick view of simulation results
- Custom motor control library
  - Design blocks
  - Easy to implement different control topologies
- Verify motor control
  - Gains from control design
  - Different control topologies
- Data can be saved for further analysis



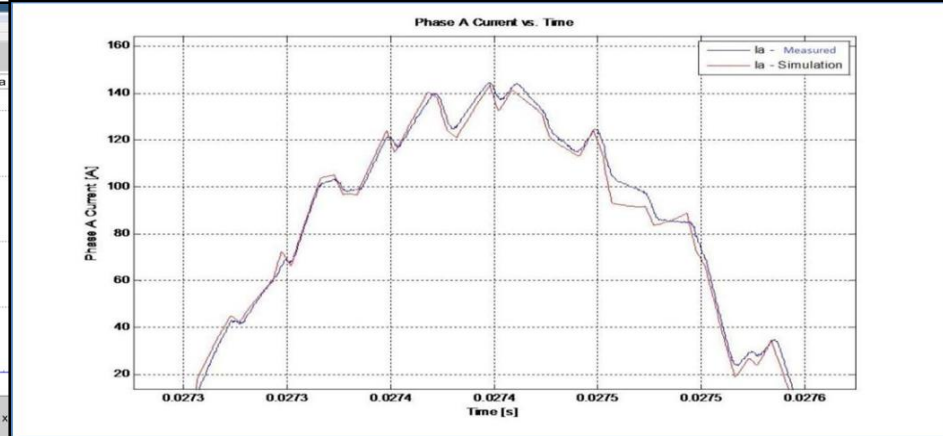
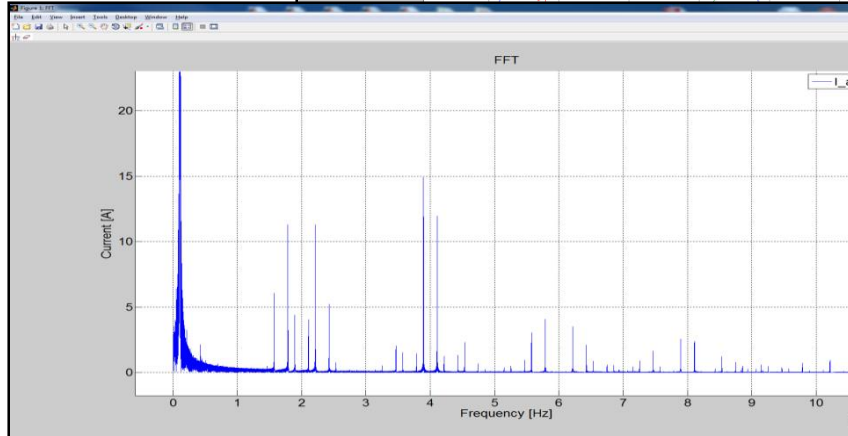
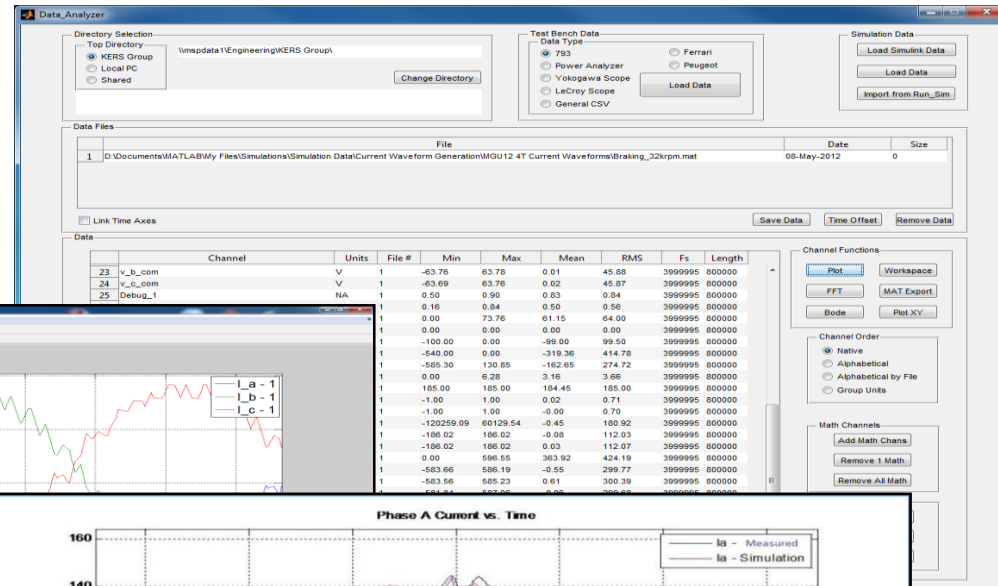
# Motor/Drive Design Process

- FEA
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- **Data Analysis/Hardware Design**
- Code Generation
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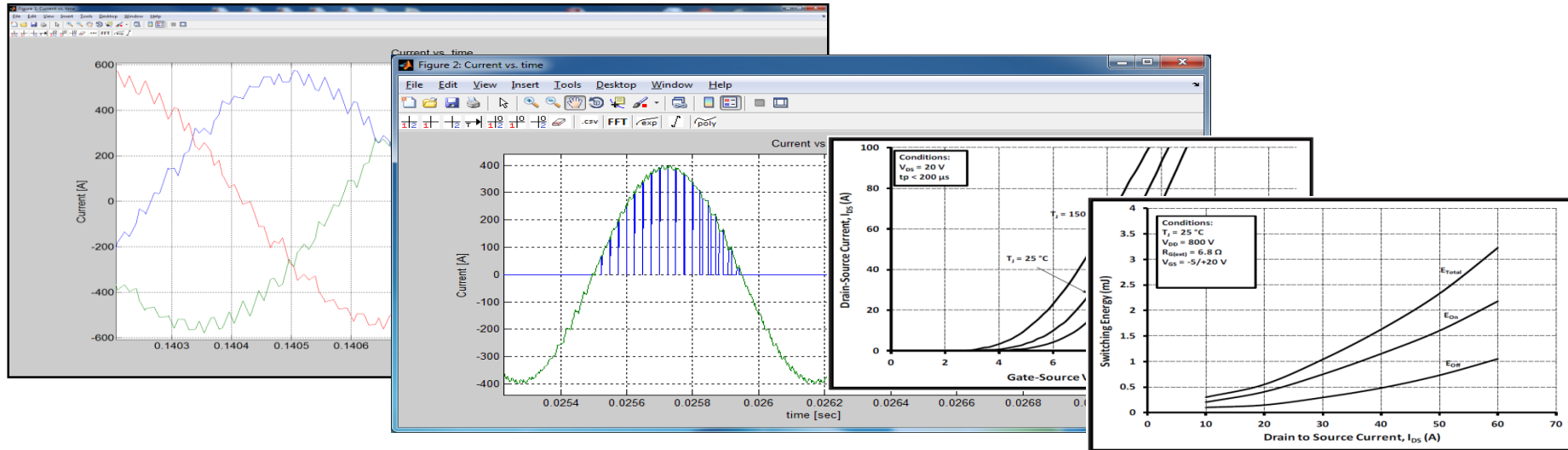
# Data Analysis

- Import simulation and experimental data
- Compare data
- Functions to analyze data



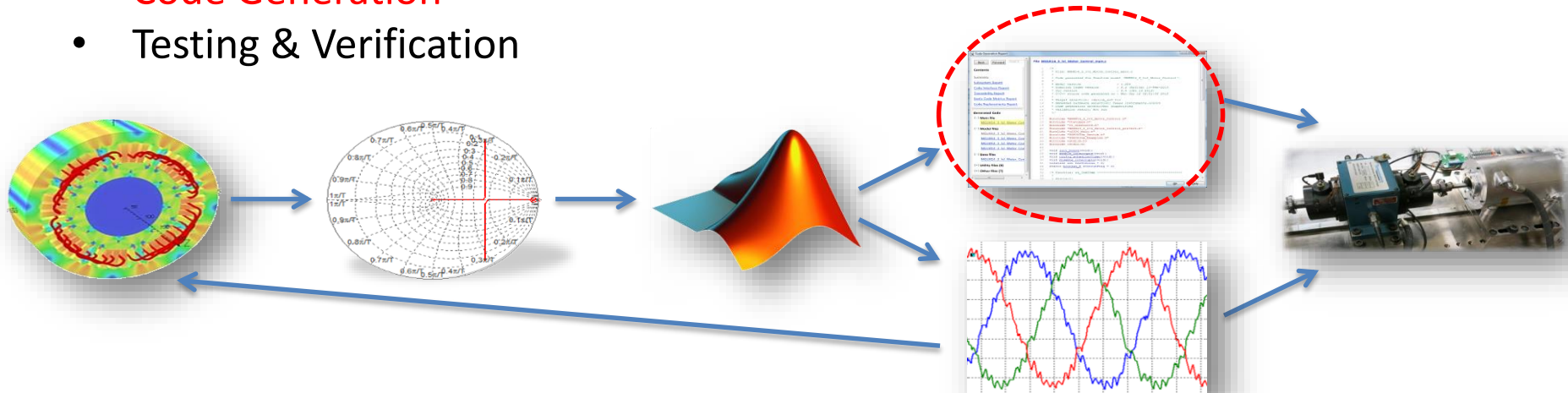
# Hardware Design

- Phase currents fed back into FEA to estimate motor losses
- Device currents used to calculate power electronics losses and heating
- DC RMS current and voltage ripple used for capacitor sizing
- RMS currents used for bus bar sizing



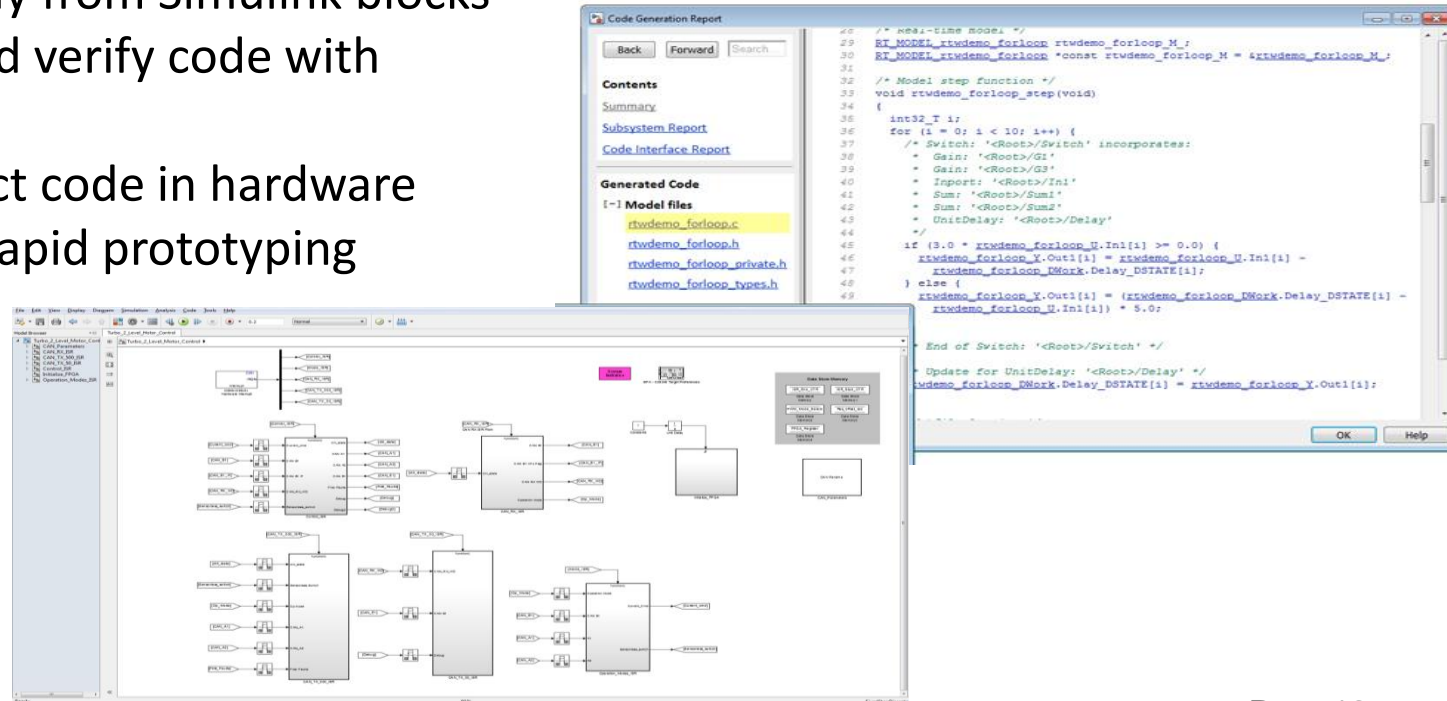
# Motor/Drive Design Process

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# Code Generation

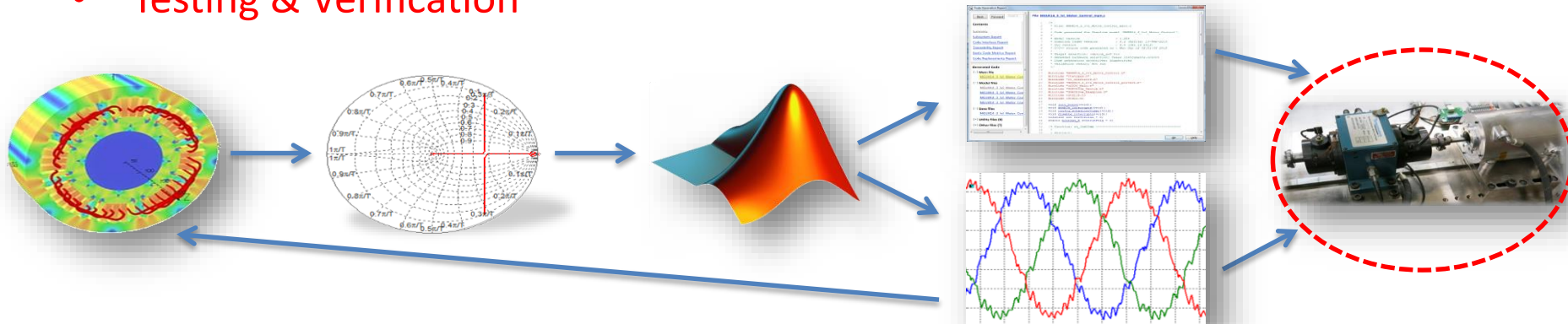
- Simulink Coder builds DSP/FPGA code directly from Simulink blocks
- Develop and verify code with simulation
- Deploy exact code in hardware
- Allows for rapid prototyping





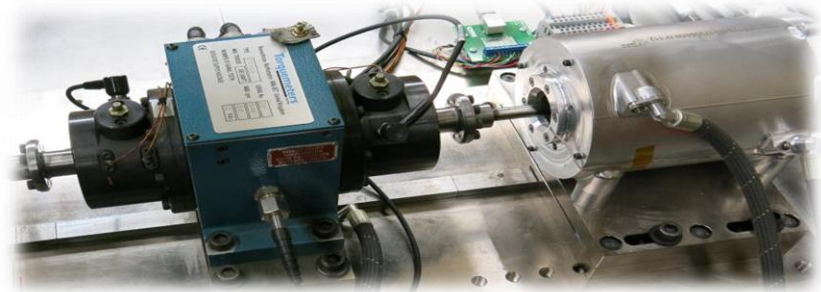
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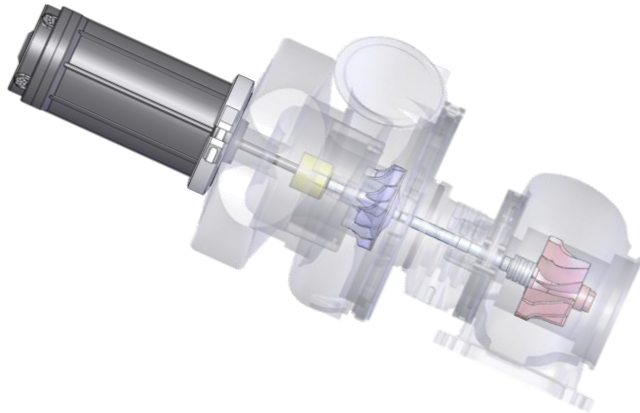


## Testing & Verification

- Calibrate drive
- Verify back-emf
- Bearings break-in
- Verify control
  - DQ current regulators
  - Field weakening,  $I_d$ ,  $I_q$
  - Torque accuracy
  - Tune sensorless control
  - Run motor to full speed and torque
- Measure motor and drive efficiency



# Applications ...



Questions Please ?



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