Ballard Power Systems

Using Simplorer® and Maxwell® Tools to Validate Electric Drives for EV Applications, and Interactions with Rapid Prototyping Tools

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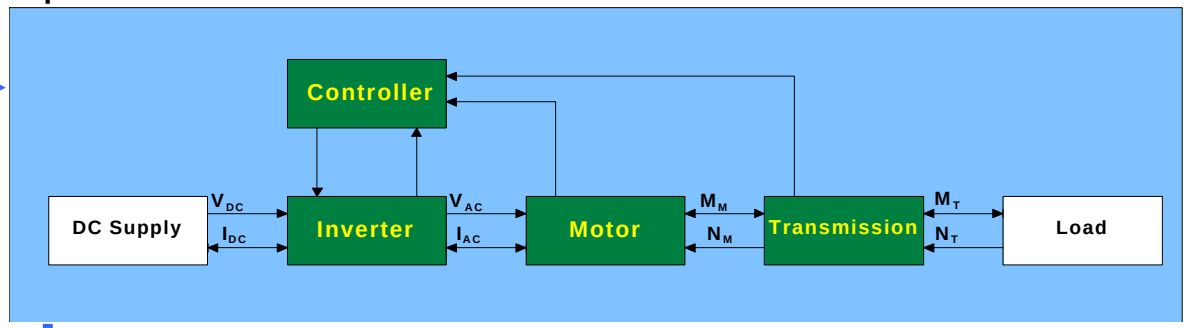
Automotive Electromechanical Simulation Workshop
9 October 2003

Electric Drives for EV Applications - Outline

- Brief Overview of Ballard
- Electric Drives Design Process
- How Ansoft Tools Fit In at Ballard
- PM Motor Design Evaluation
- Control Design ←→ Motor Design
- Inverter Design ←→ Custom Power Module Design
- Rapid Prototyping ←→ Control Design
- Testing ←→ Motor Design Evaluation

Electric Drives Design Process

Customer Specification



Transmission Assumptions

Motor Requirements

Motor Electromagnetic Design

Motor Mechanical Design

Motor Thermal Design

Inverter Requirements

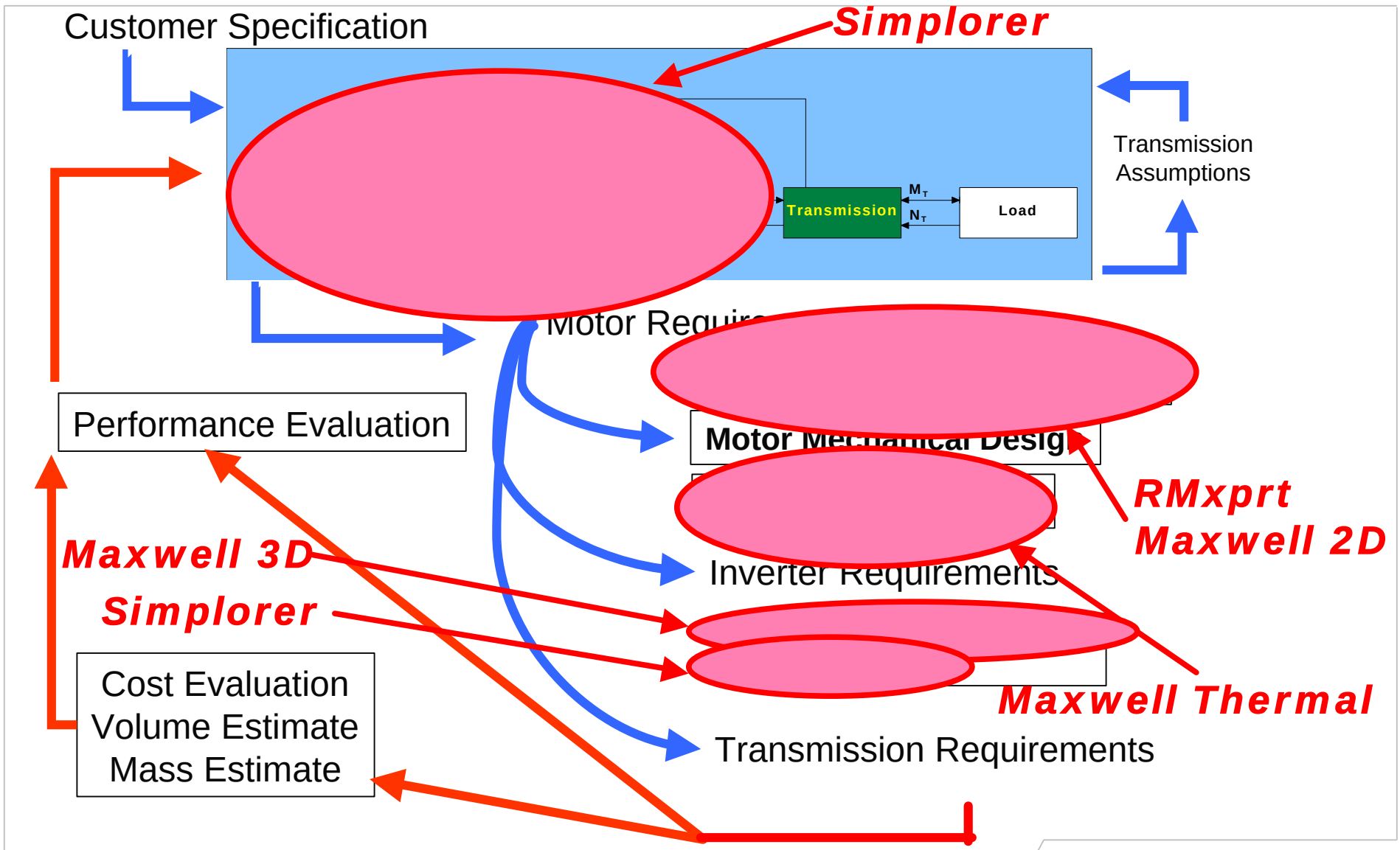
Custom Power Module Design
Inverter Design

Transmission Requirements

Performance Evaluation

Cost Evaluation
Volume Estimate
Mass Estimate

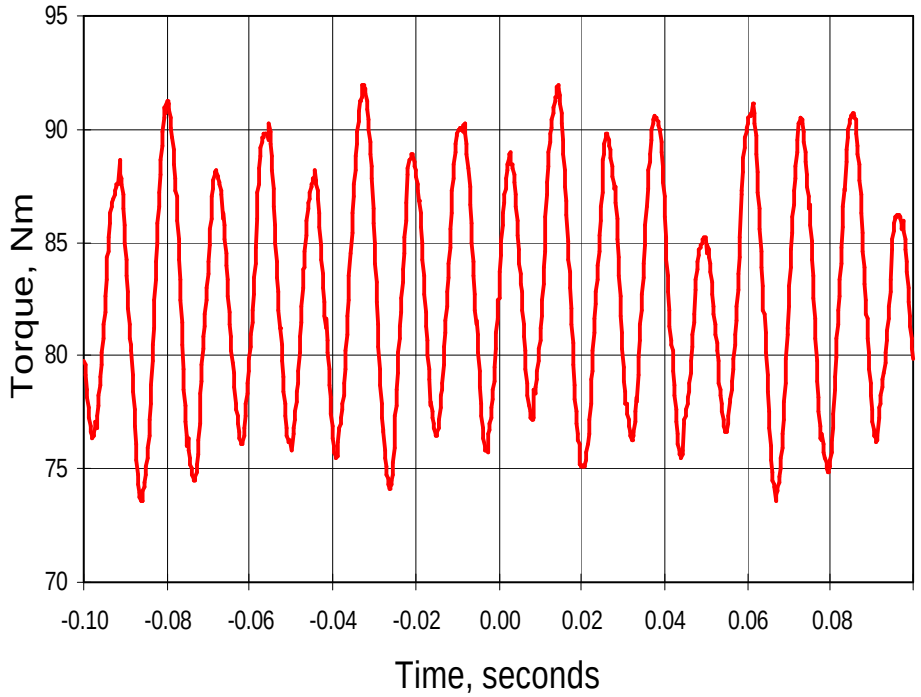
How Ansoft Tools Fit in at Ballard



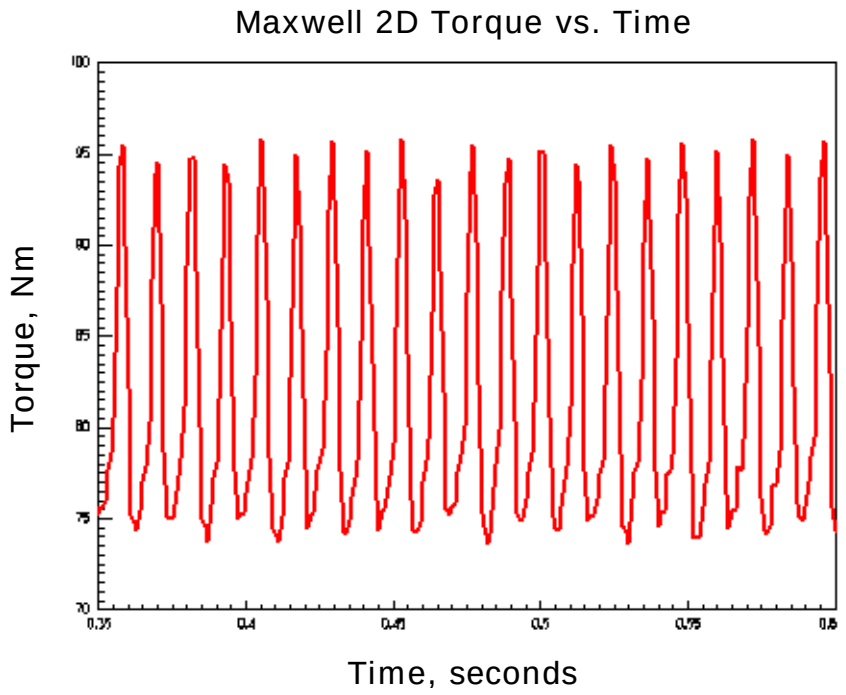
PM Motor Design Evaluation

- Maxwell 2D used to perform analysis
  - Calculation of Average Torque and Ripple Torque
    - Average value and peak-to-peak magnitude match well between test and FEA calculations.

Test Data (2.8 revolutions)



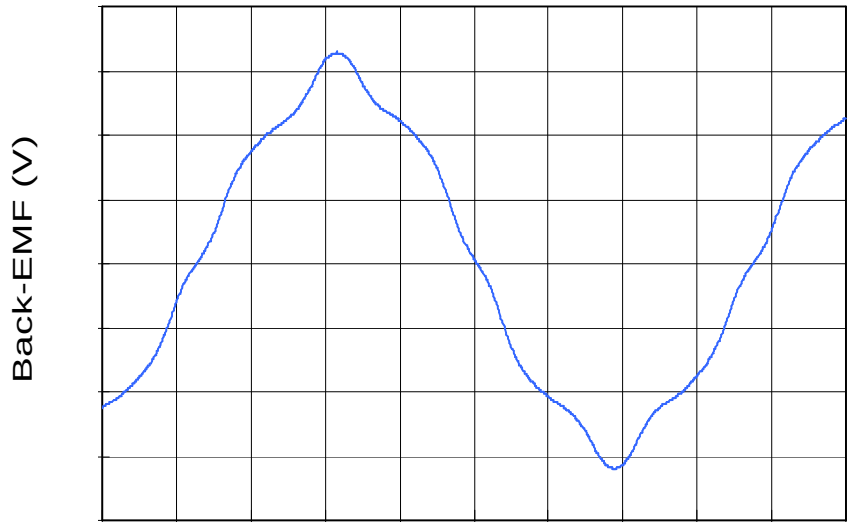
FEA Results (3.7 revs)



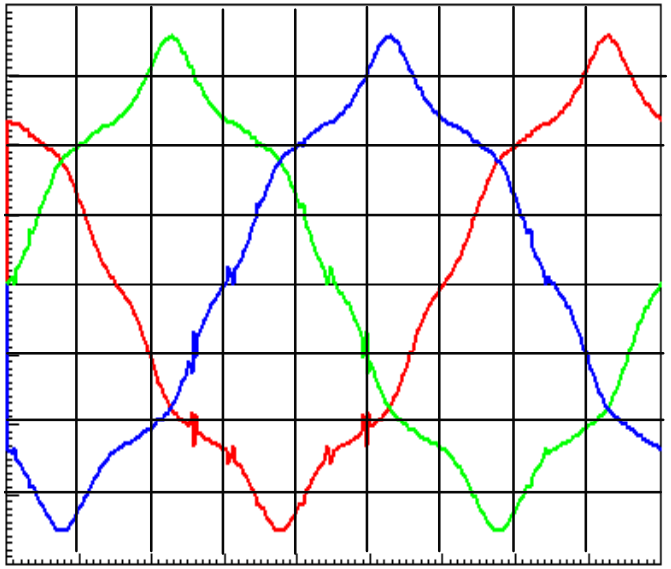
PM Motor Design Evaluation

- Maxwell 2D used to perform analysis
  - Calculation of Back EMF
    - Harmonic content and magnitude matches well with experiments.

Test Data



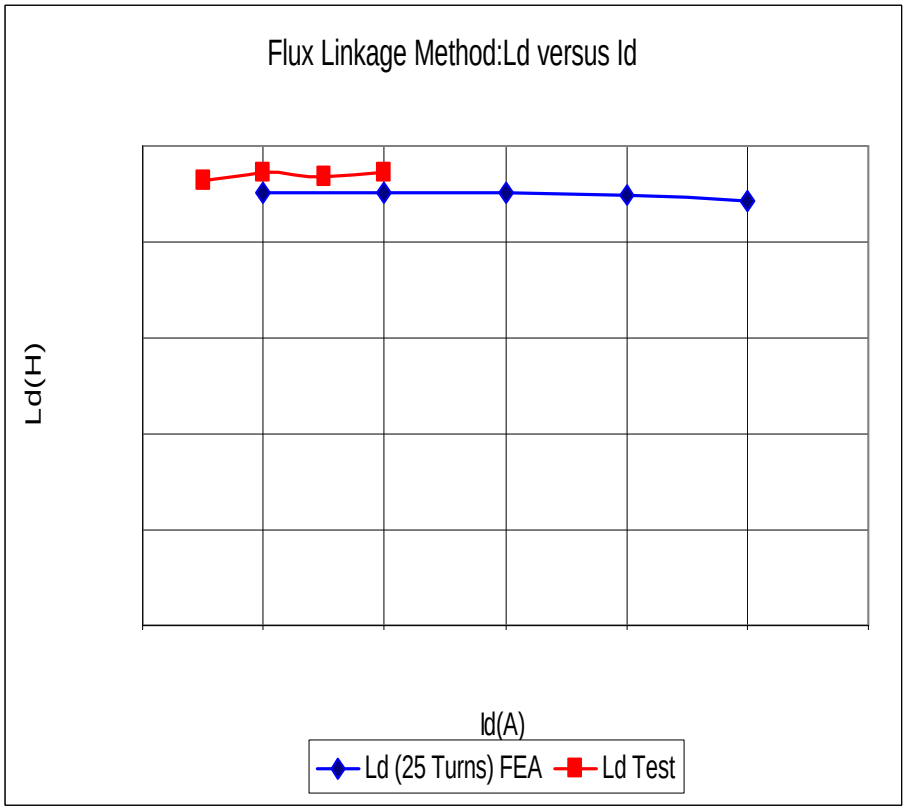
FEA Results

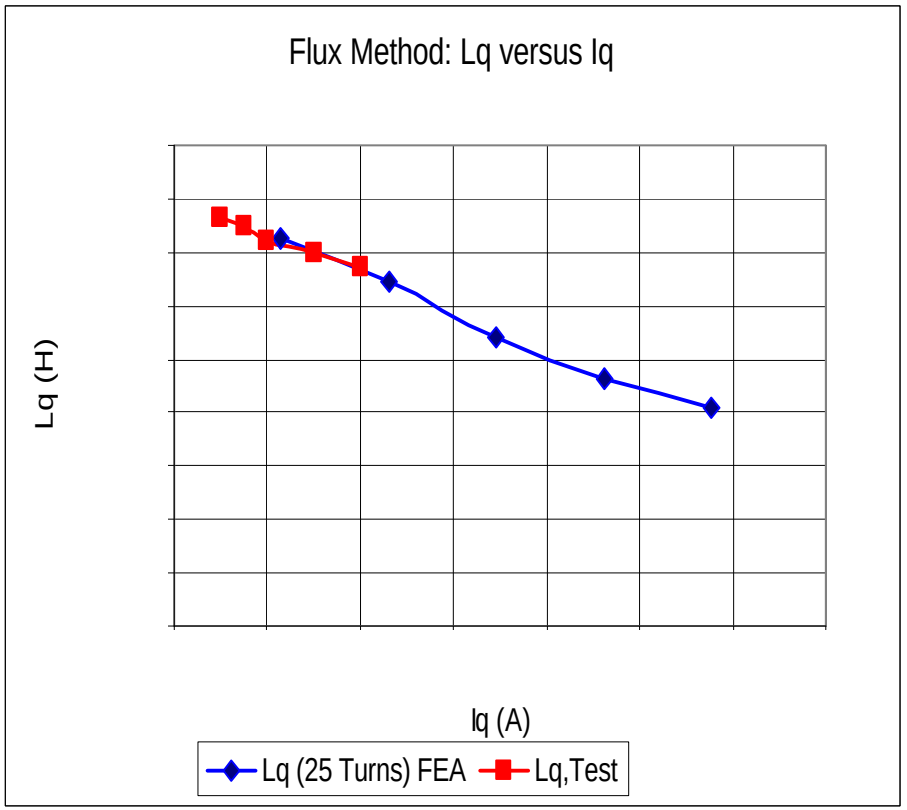


Equal time and voltage scales

PM Motor Design Evaluation

- RMxprt used to enter motor design information
- Maxwell 2D used to perform analysis
  - Calculation of L_d and L_q (Energy or Vector Potential Method)





Control Design ←→ Motor Design - General

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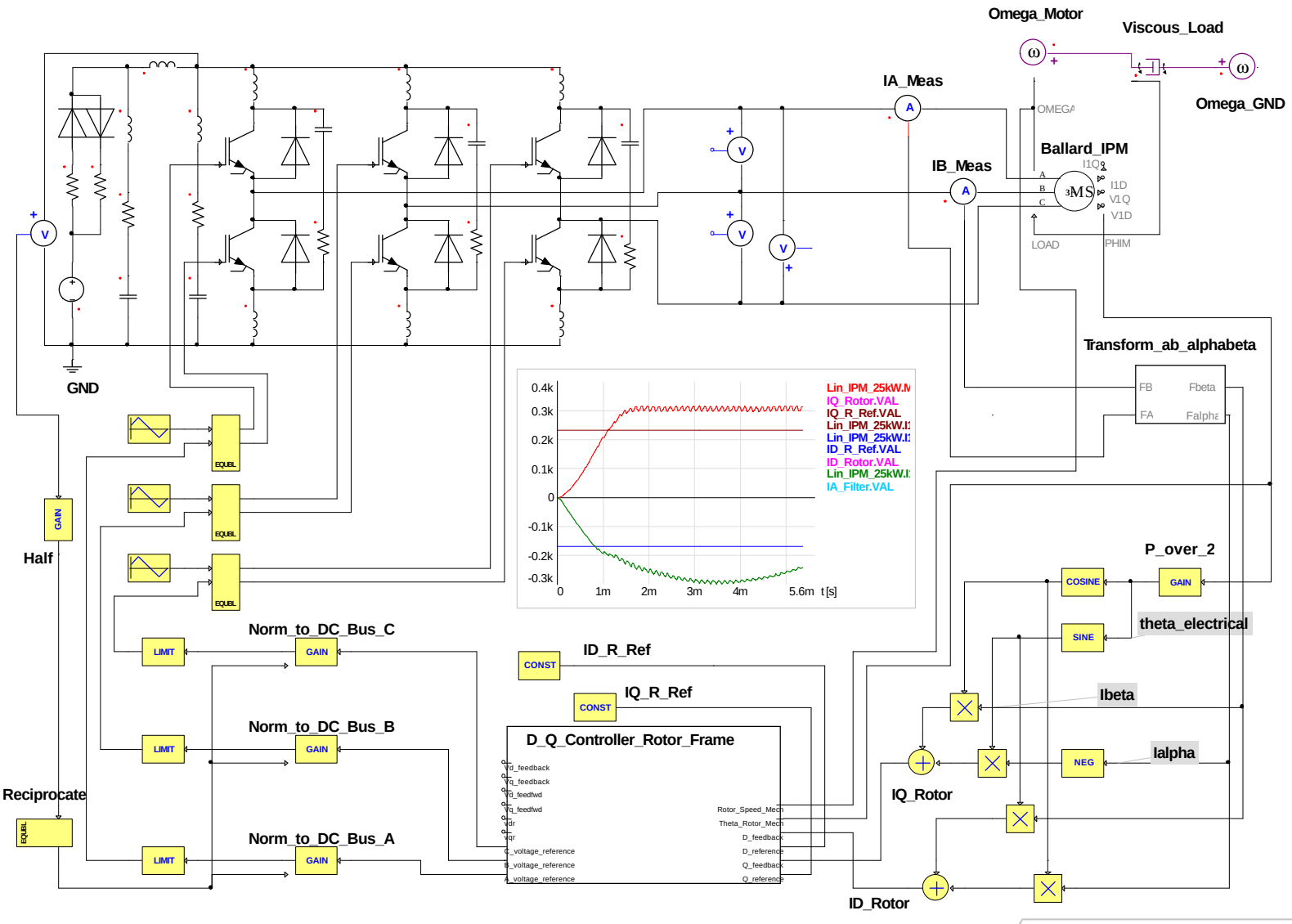
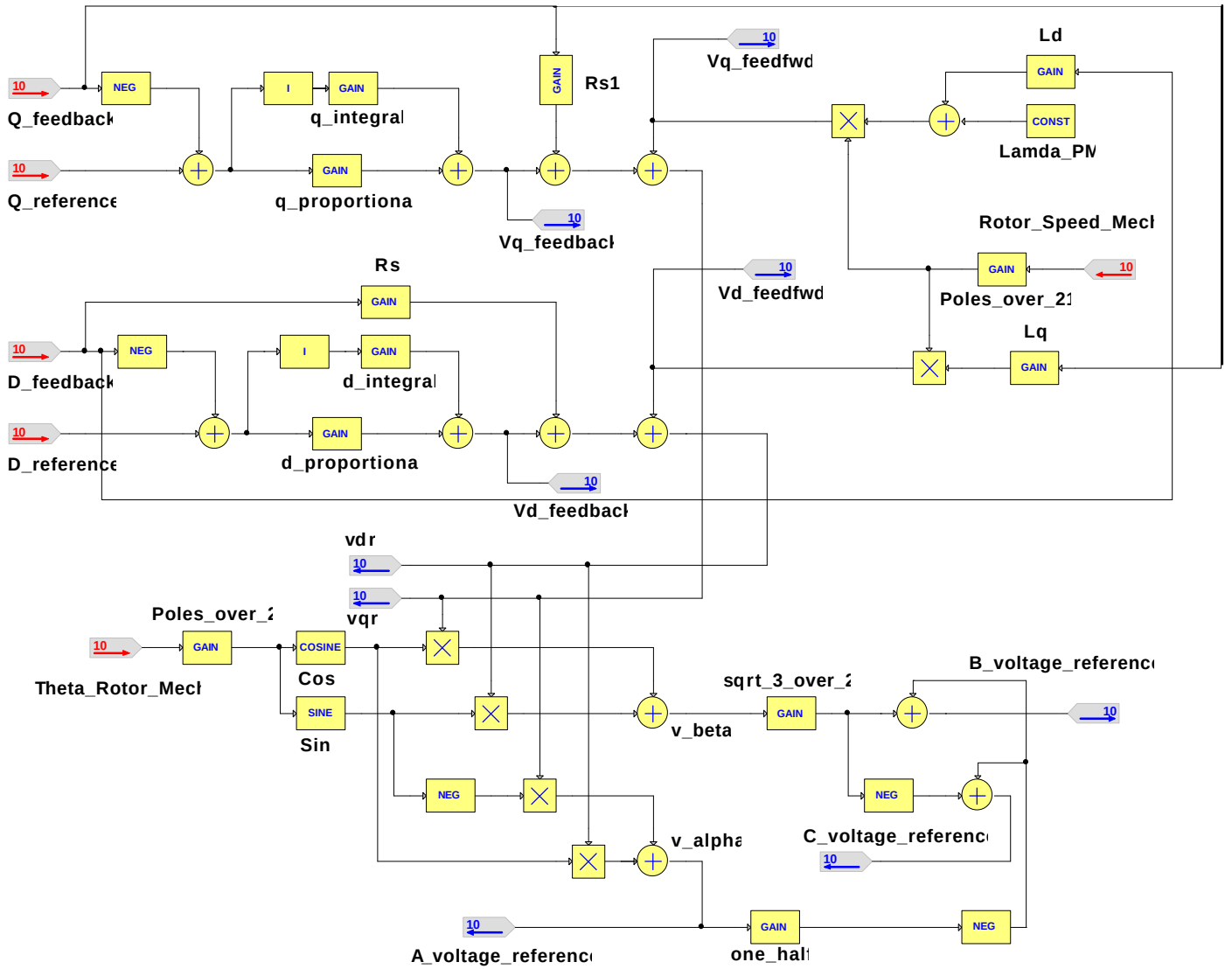
- Motor equivalent circuit parameters – with saturation
  - Needed for control development
  - Use Maxwell 2D to update estimates made earlier in design process
  - Used to populate Simplorer model of PM motor
- Ansoft tools are used to explore and understand:
  - PTPA (selection of i_d/i_q trajectories) – Maxwell & Simplorer
  - Field weakening control – Maxwell & Simplorer
  - Interactions of control with dc bus variations due to load point changes (dynamic) - Simplorer
  - Interactions of sensors and interface limitations on control performance – Simplorer
  - Etcetera
- Matlab/Simulink used as primary control development tool with autocode function for dSpace rapid prototyping hardware.

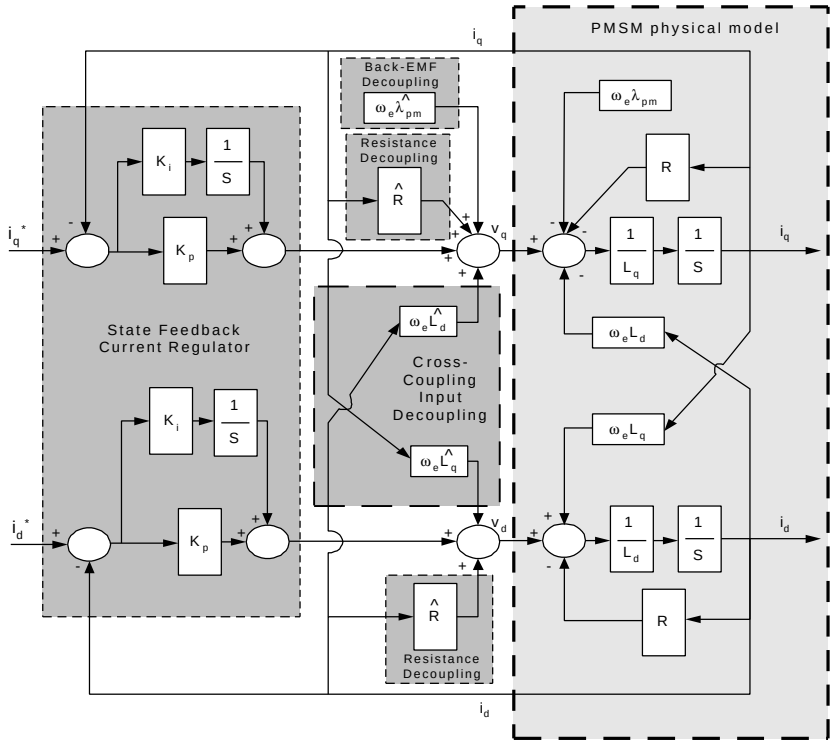
Control Design ←→ Motor Design - Simplorer



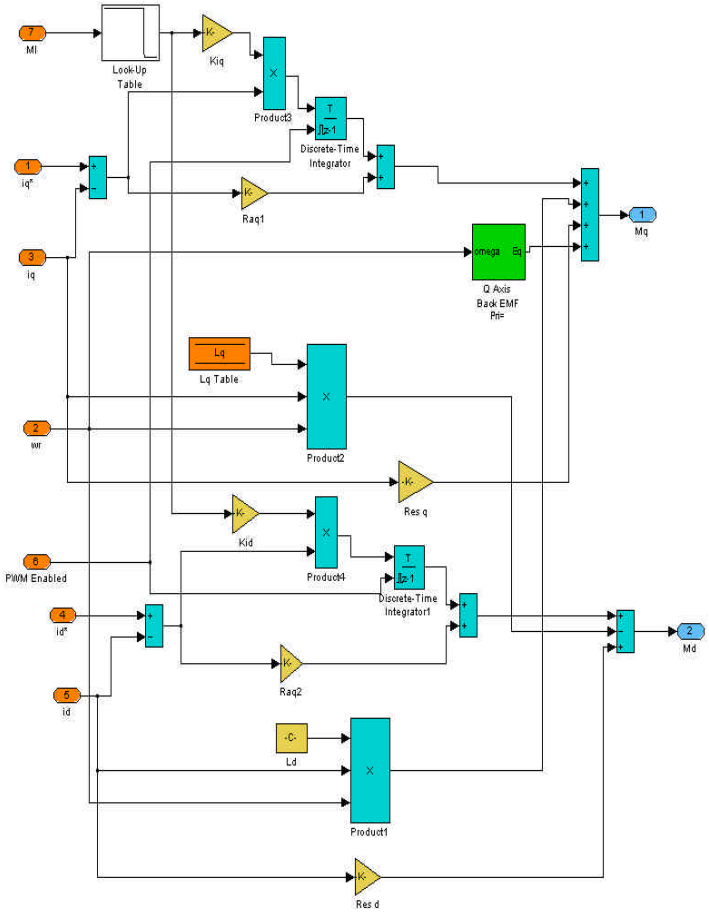
Control Design ←→ Motor Design - Simplorer



Control Design ←→ Motor Design – Co-simulate



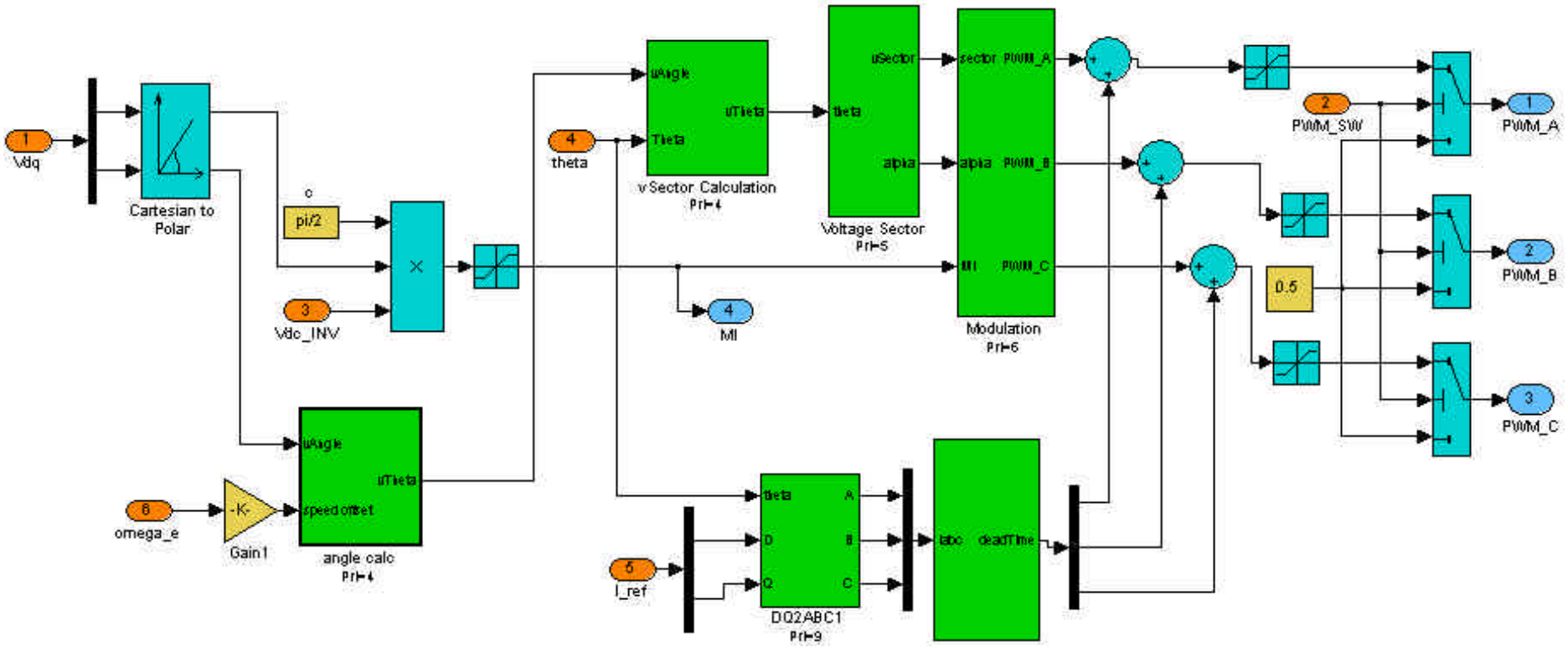
Current Regulator/Motor Block Diagram



Simulink Current Regulator

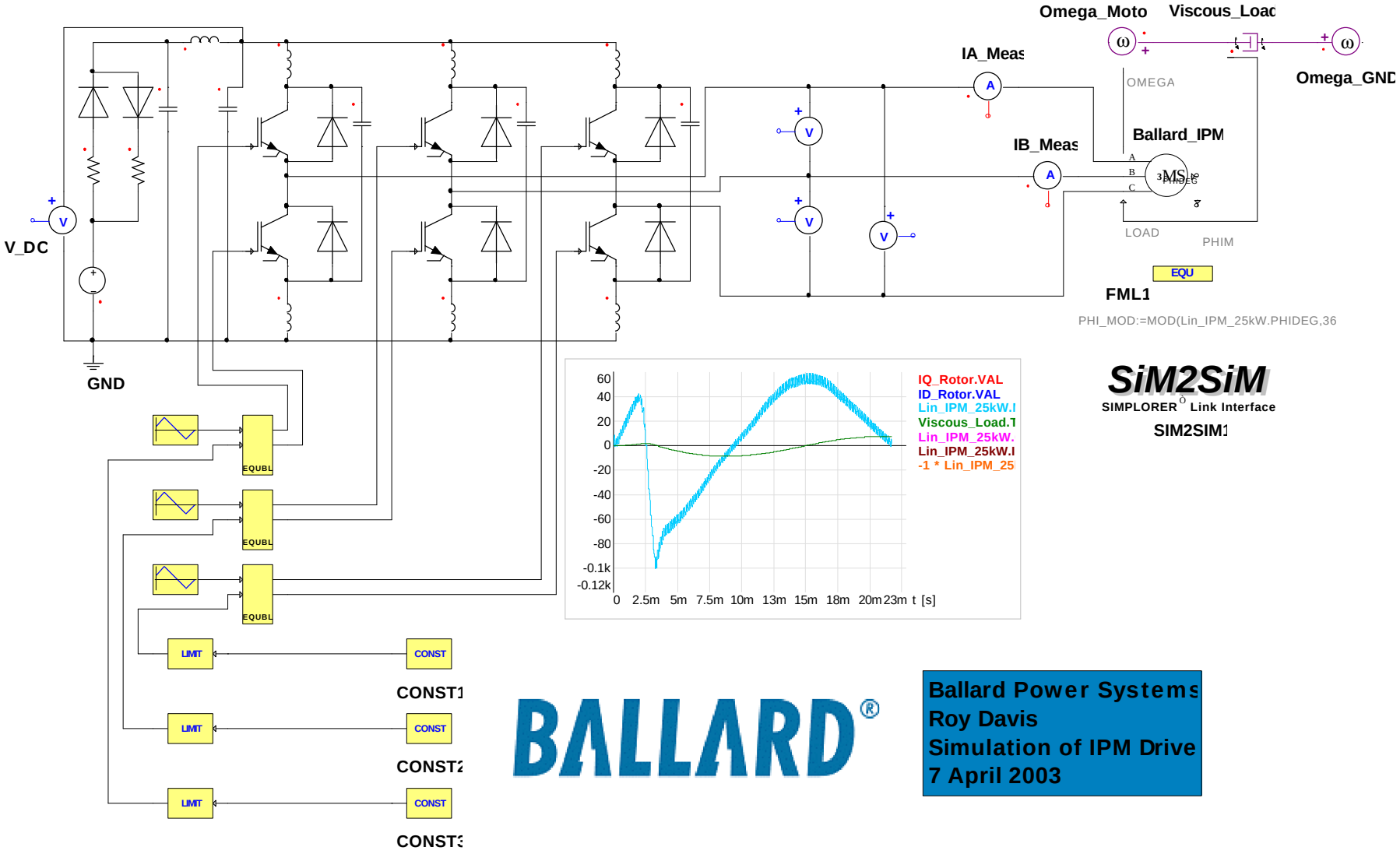
Control Design ←→ Motor Design – Co-simulate

- Space Vector Modulation (SVM) with Overmodulation Modes 1-2 and Deadtime Compensation



Simulink Model of Modulation Systems

Control Design ←→ Motor Design – Co-simulate



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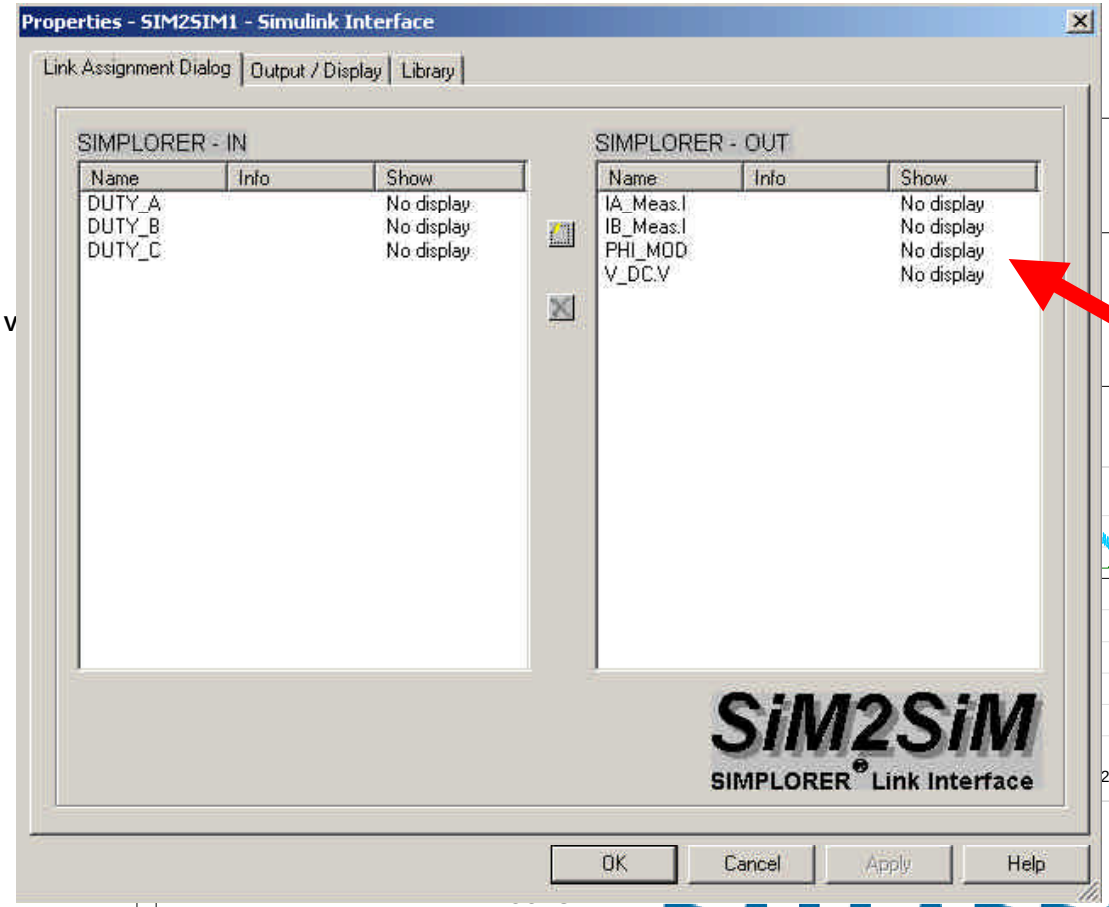
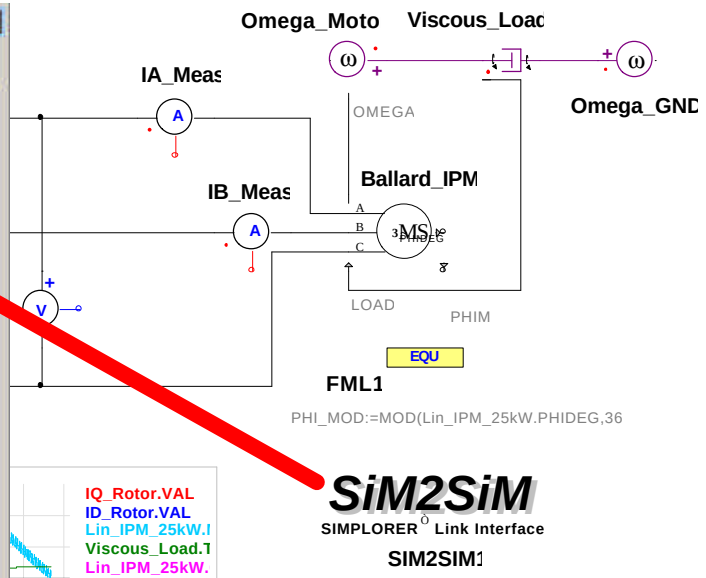
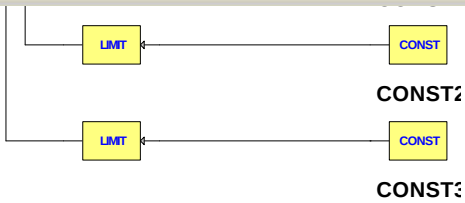
Simulation of IPM Drive
7 April 2003

Control Design ←→ Motor Design – Co-simulate







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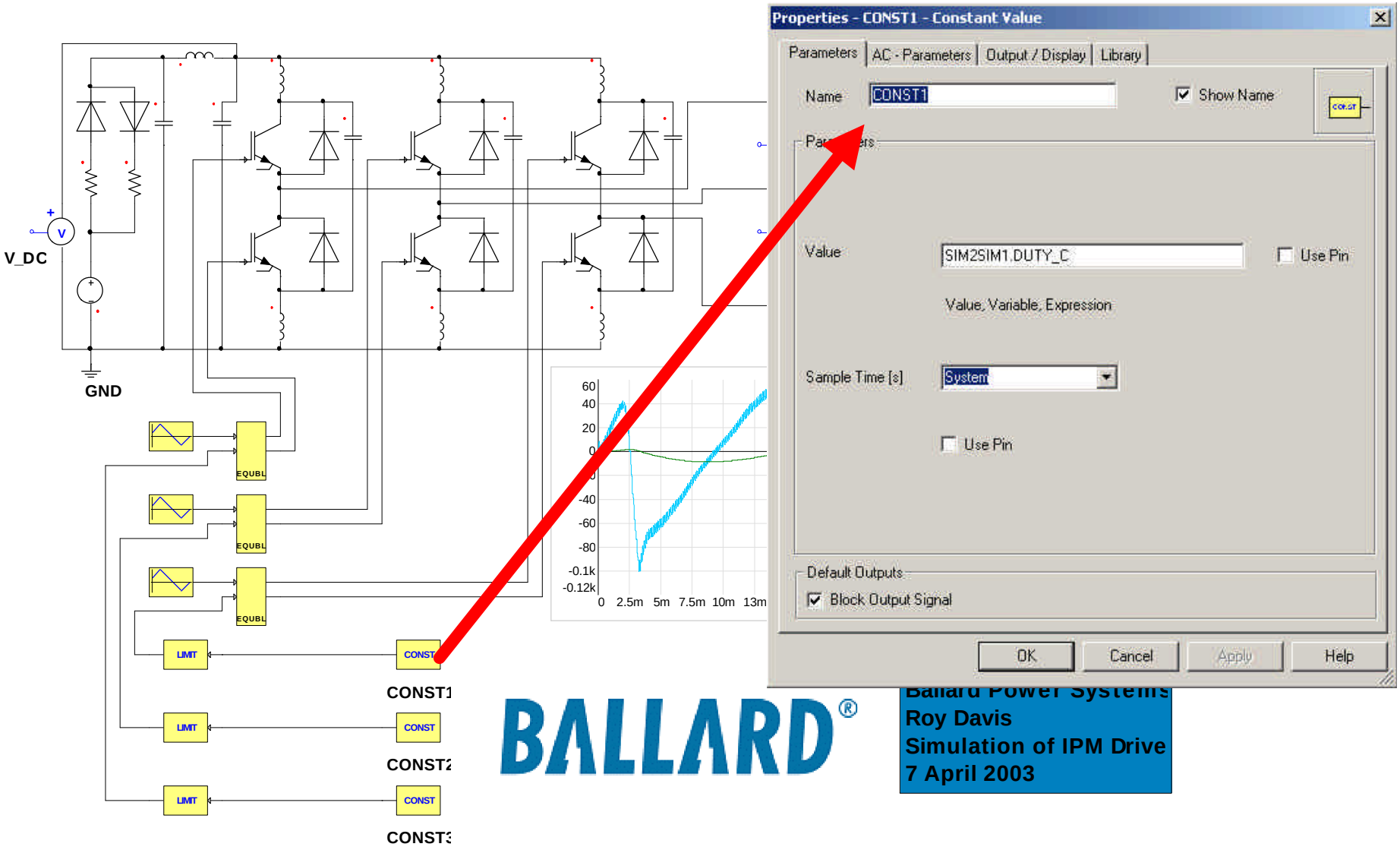
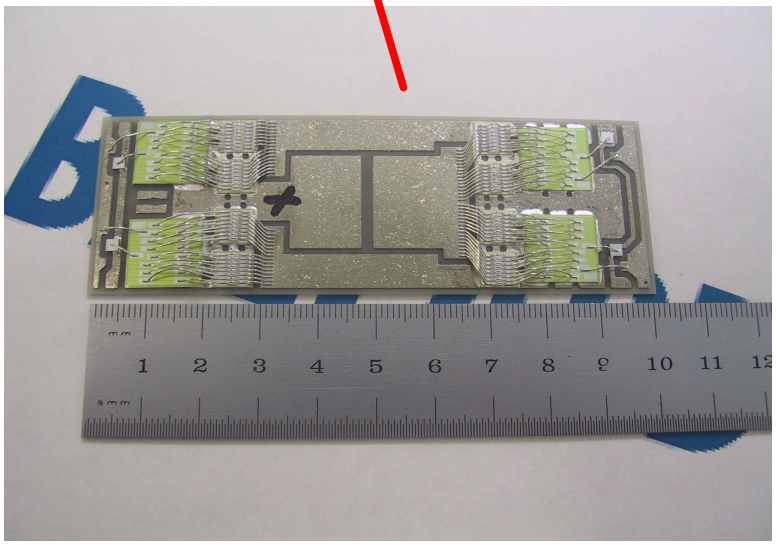
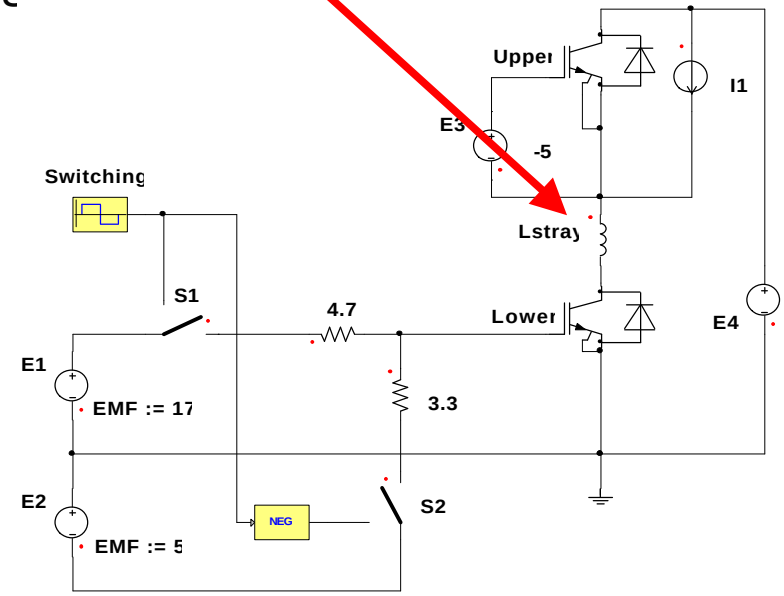


Inverter Design ←→ Custom Power Module Design

- Use Maxwell 3D to model power module layout
  - Objective is to compute parasitic module inductance to support module design layout decisions
  - 2nd objective is to provide inductances for bridge circuit simulation
  - Presently developing this process – difficult to get accurate results





- Also developing process for parameterizing the detailed models of IGBTs in Simplorer using this test circuit.

Inverter Design ←→ Custom Power Module Design

- Simplorer model of inverter, dc source, and motor used to:
  - Evaluate component stresses under realistic conditions
    - Switches
    - Diodes
    - Capacitors
  - Investigate effects of different/variable PWM algorithms
  - Determine losses

Rapid Prototyping ←→ Control Design

- We use dSpace for rapid prototyping control design and motor performance evaluations on the dyno
  - Clean interface to Simulink/RTW with Control Desk
- Simplorer model of motor and inverter easily integrated with Simulink model of control
  - Helps to debug any problems arising from interactions with inverter
  - PM motor model easily allows use of saturable inductances as functions of current
  - Easy to do what-if investigations
  - Much easier and seemingly more reliable than Matlab Power System Toolbox to include detail model of inverter and PM motor.

Testing ←→ Motor Design Evaluation

- Unexplained or different behavior that occurs during testing can be examined in Maxwell or Simplorer to determine cause.
- Provides a feedback link to design tool usage that allows refinement of “rules of thumb” or development of design rules to be applied with the numerical design tools.