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A Power-hardware-in-the Loop Test Bench for Electric Machine Emulation

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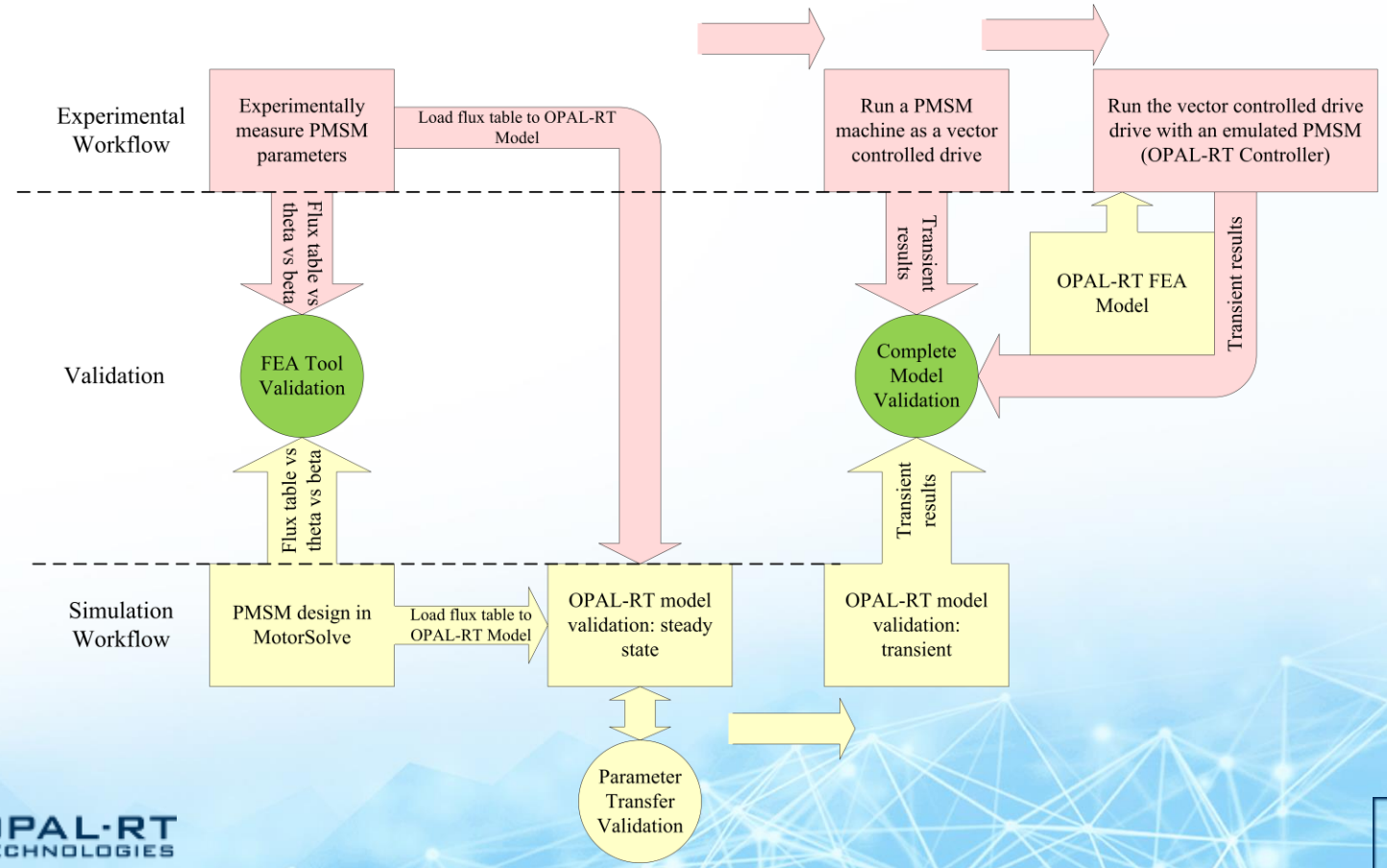
Outline

- Motor model validation: tool-flow
- MotorSolve data import
- Machine emulator structure and control
- Experimental setup (switched and linear machine emulators)
- Summary

Motor model validation: tool flow



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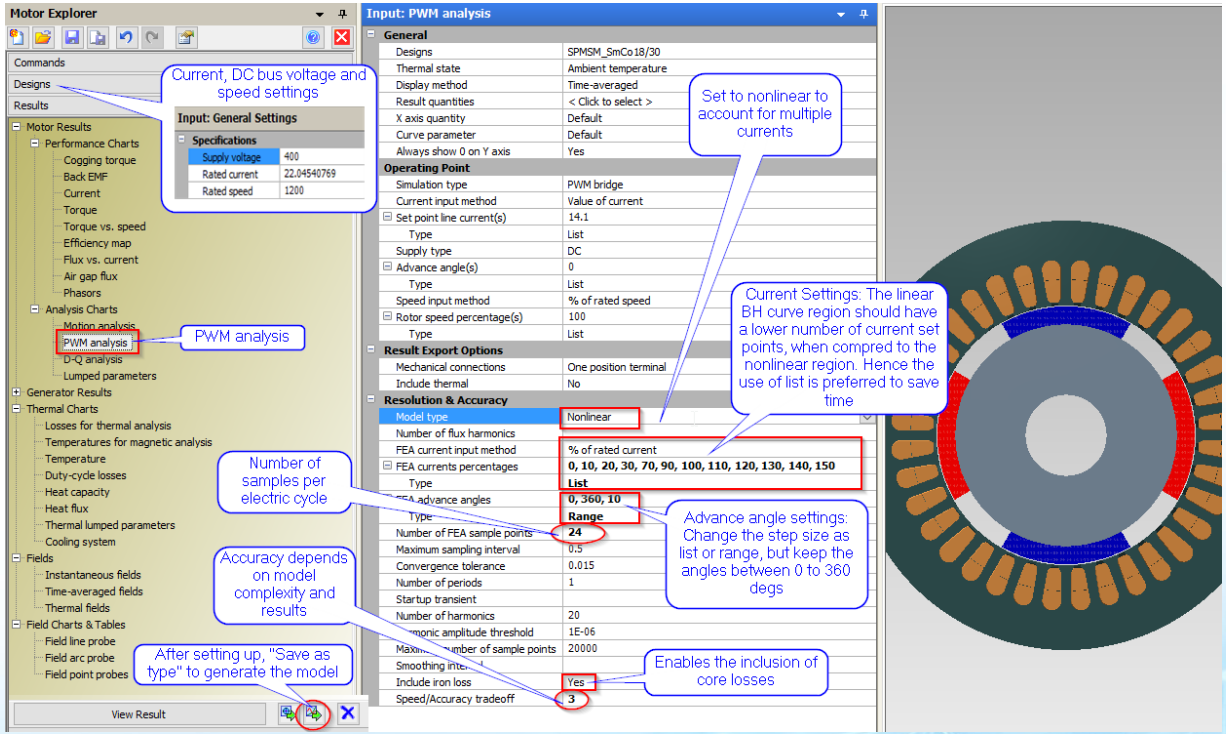
Motor data export: MotorSolve to OPAL-RT



- Process of data export from MotorSolve

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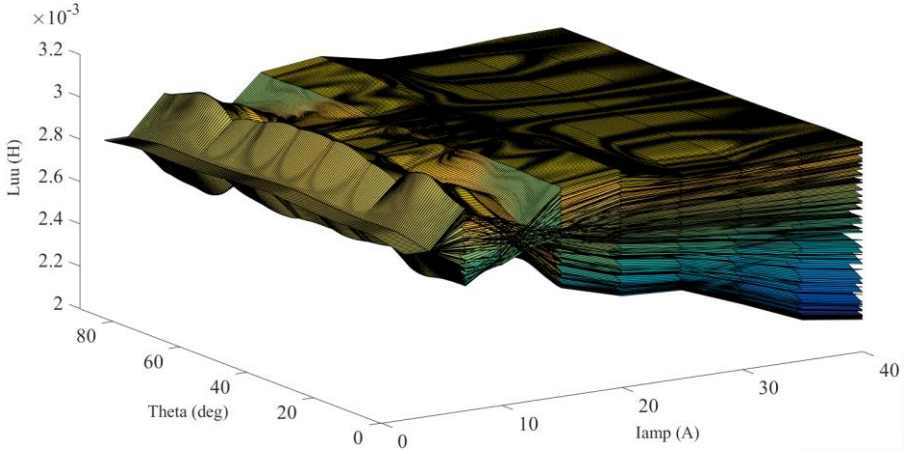
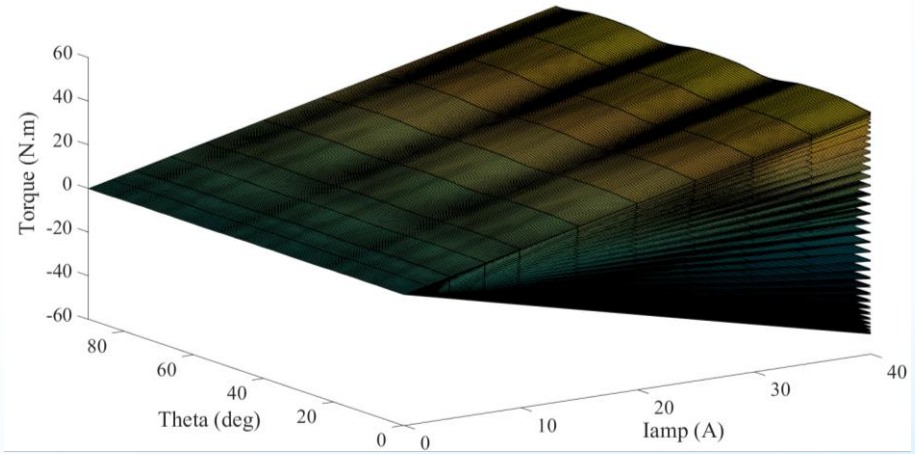
Motor data export: MotorSolve to OPAL-RT





- Machine geometric and magnetic data exported from the FEA software MotorSolve, to the behavioural model in OPAL-RT

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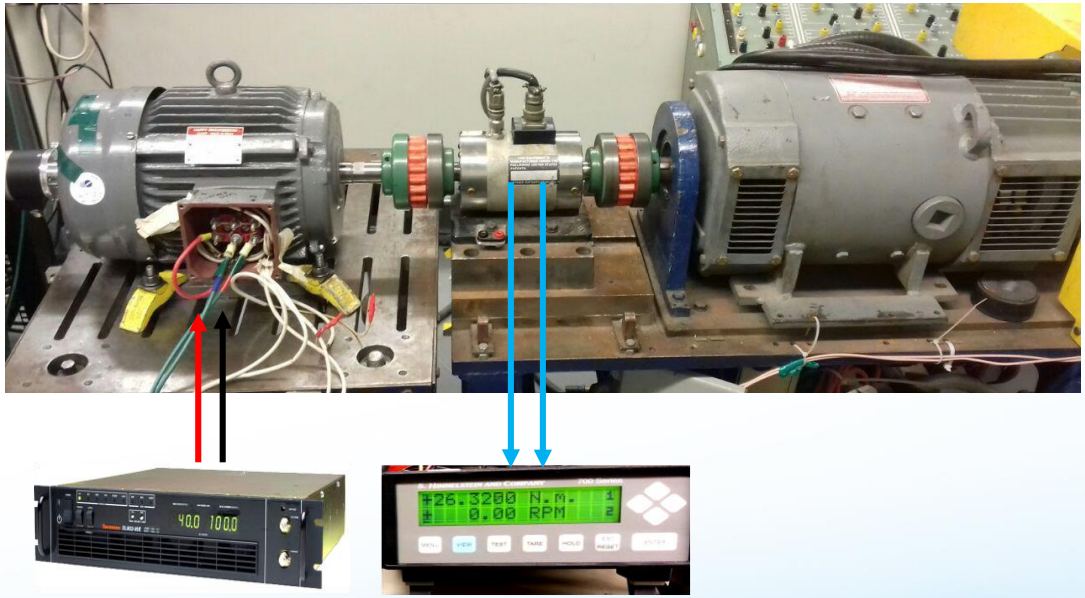
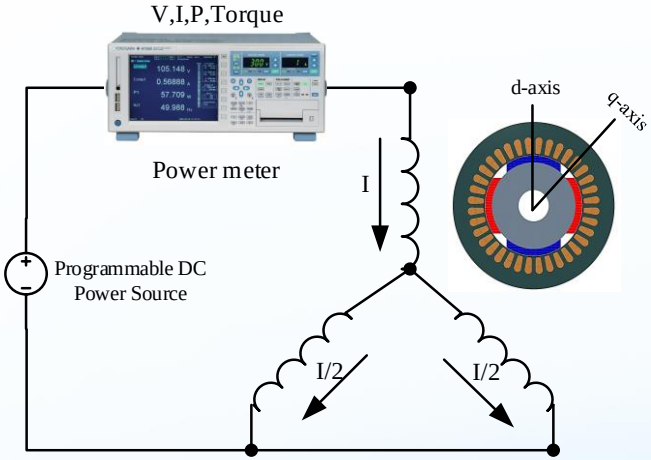
Physical measurement of machine data*

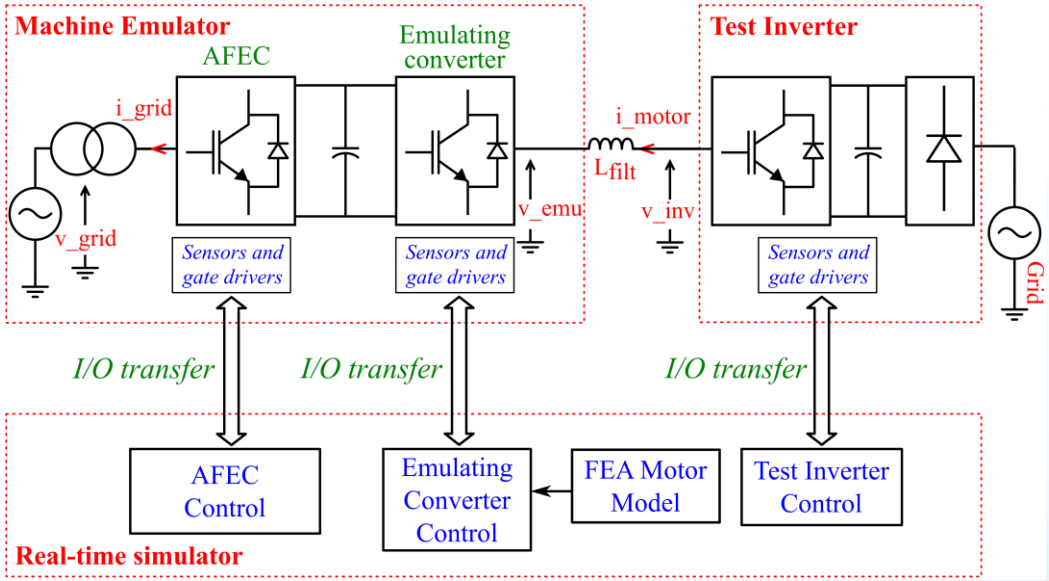




- Experimental setup for measuring machine geometric and magnetic data

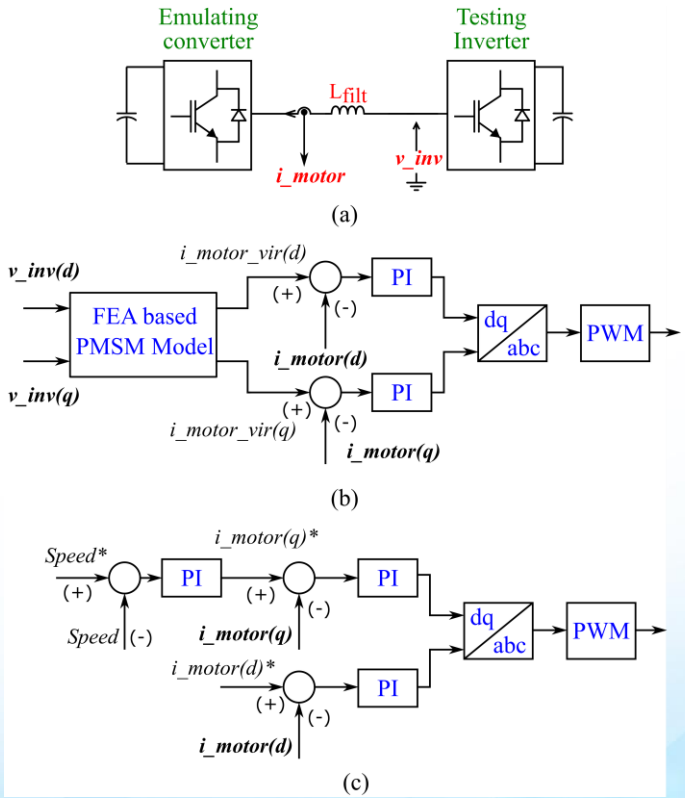
* Courtesy: Chirag Desai

Machine emulator structure



- The active front end converter and the emulating converter connected in a back-back fashion works as a power amplifier, emulating the machine behaviour

Machine emulator – control structure



- The emulating converter and the test inverter both work in current control mode
- Controller instability of the system, is avoided by keeping the bandwidth of the emulating converter much higher than the test inverter
- The L-filter (in the figure) is just a link filter used for interconnection of the machine emulator with the test inverter

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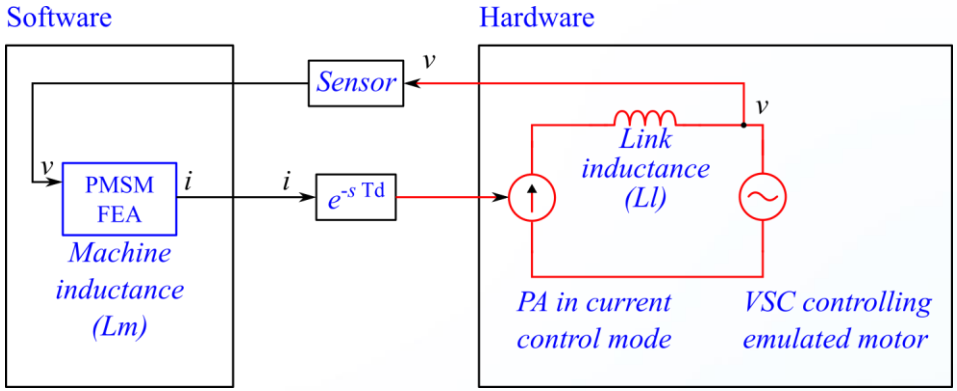
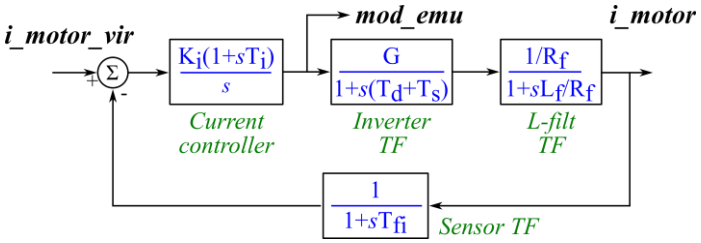
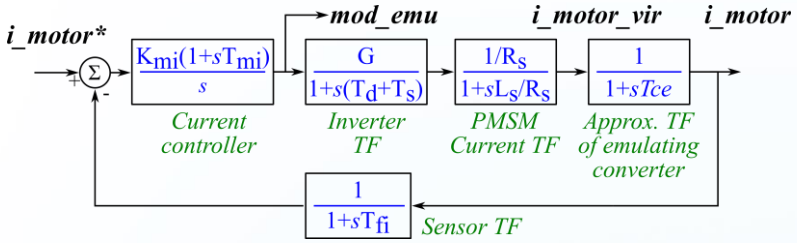
Machine emulator - interface algorithm



- The interface algorithm used is current-type ideal transformer model (ITM)
- The delay *'Td'* is inclusive of the power amplifier delay and the time-step of the real-time simulator; power amplifier delay (if linear) is almost negligible
- L_l needs to be smaller than L_m to ensure absolute stability; however the PA current control loop BW and the test inverter current control loop BW have a role as well

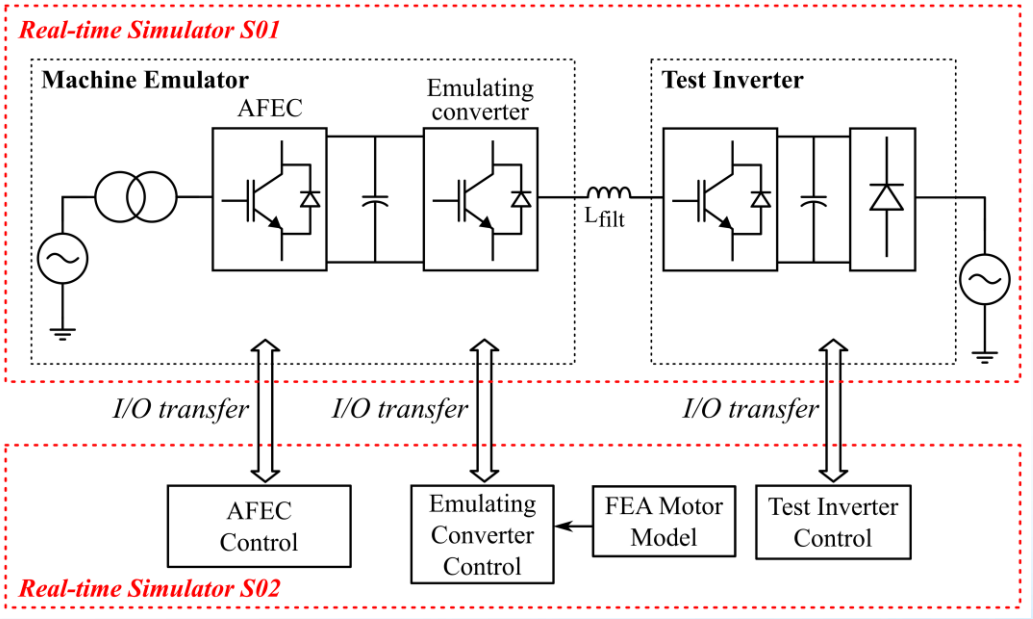
Machine emulator – control structure





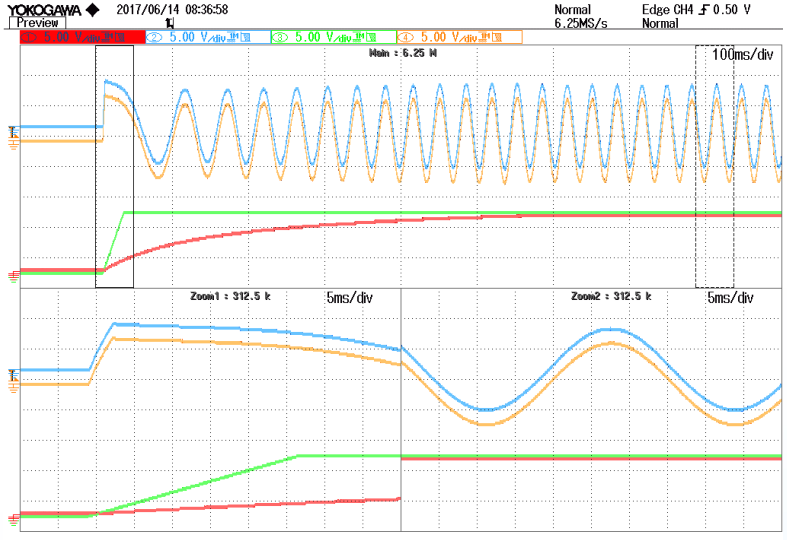
- Emulating converter working in current control mode, cancels dynamics associated with the link inductor
- Emulating converter current control loop needs to be much faster (at least five times) than the test inverter inner current loop to ensure stable operation

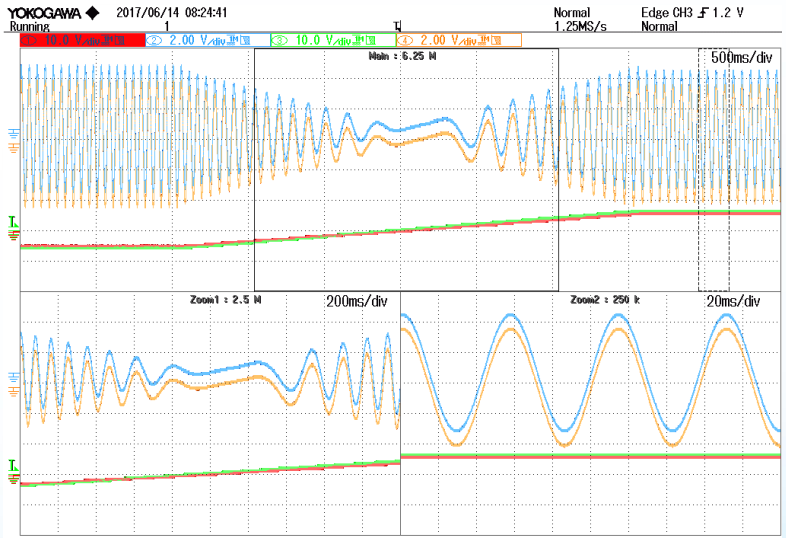
Machine emulator – real-time simulation



- System implemented in a C-HIL simulation on two OPAL-RT simulators (OP4510s)
- The PMSM-SH model uses MotorSolve flux and torque tables

Machine emulator – real-time simulation





- Results show a stable real-time simulation validating of the individual constituent converters. The same control can be further used for the experimental PMSM setup as well, when developed

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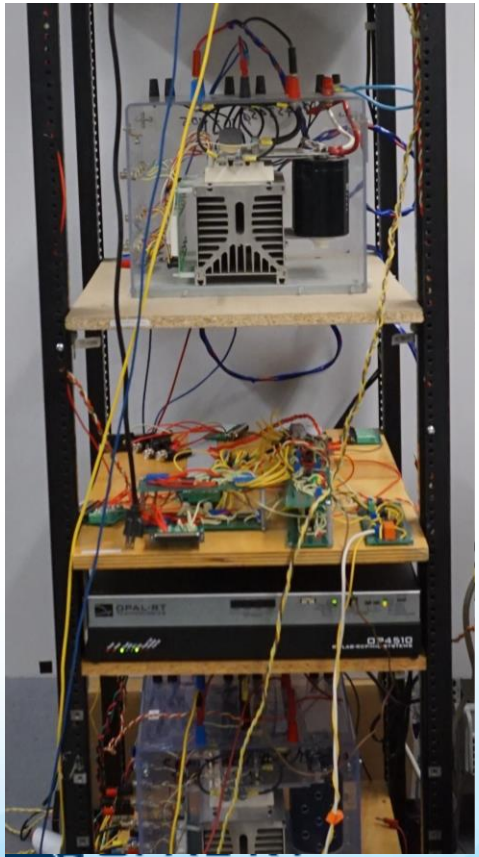
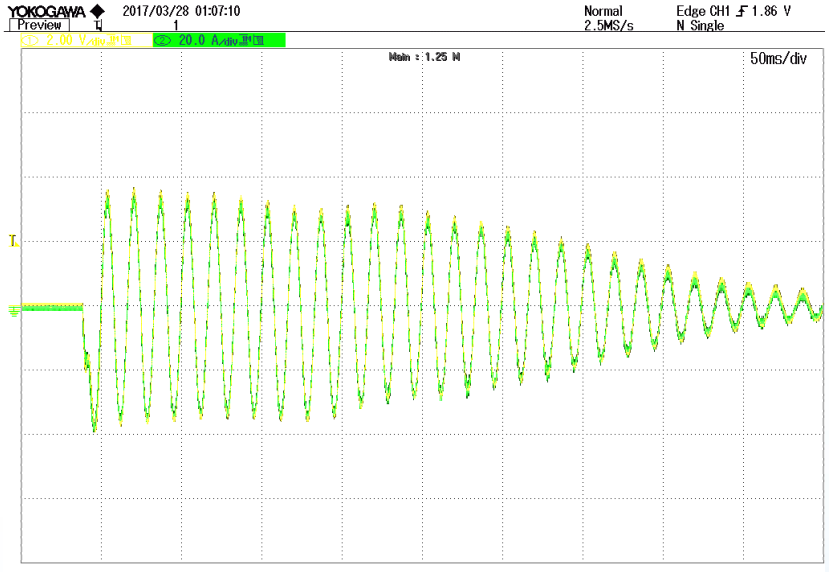
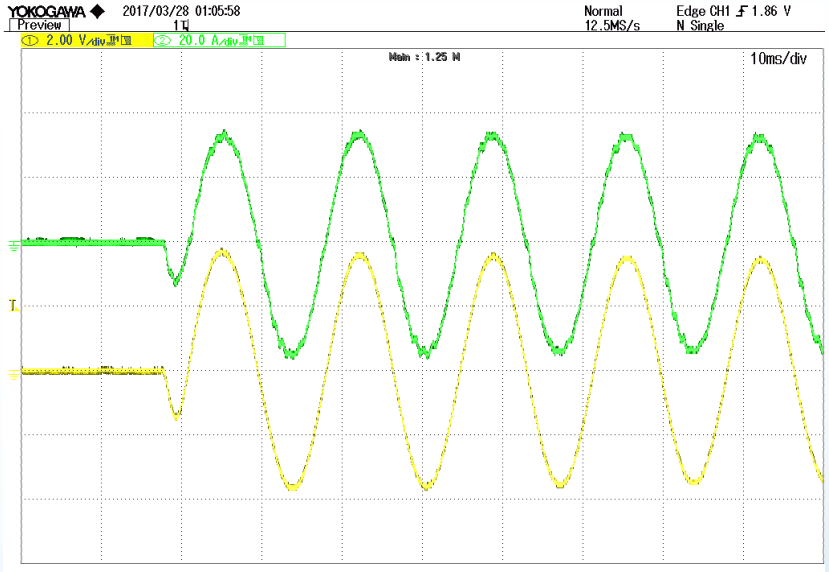
Power amplifier - switched



- The power amplified developed using simple 6-pack VSC based converters, each switching at 20 kHz
- The power amplifier has a an emulation capability of 15 kVA (implying a machine emulation of around 12-15 hp as well.
- Machine amplifier designed to have a current loop bandwidth of around 2 kHz
- Protection circuitry is developed for the power amplifier/ machine emulator to protect against overcurrent and overvoltage faults, transformer for isolation

Power amplifier - switched





- Preliminary results relating to induction motor direct online startup
- Emulated machine draws a peak inrush current of up to 40 A and mimics the simulated machine model (yellow trace)

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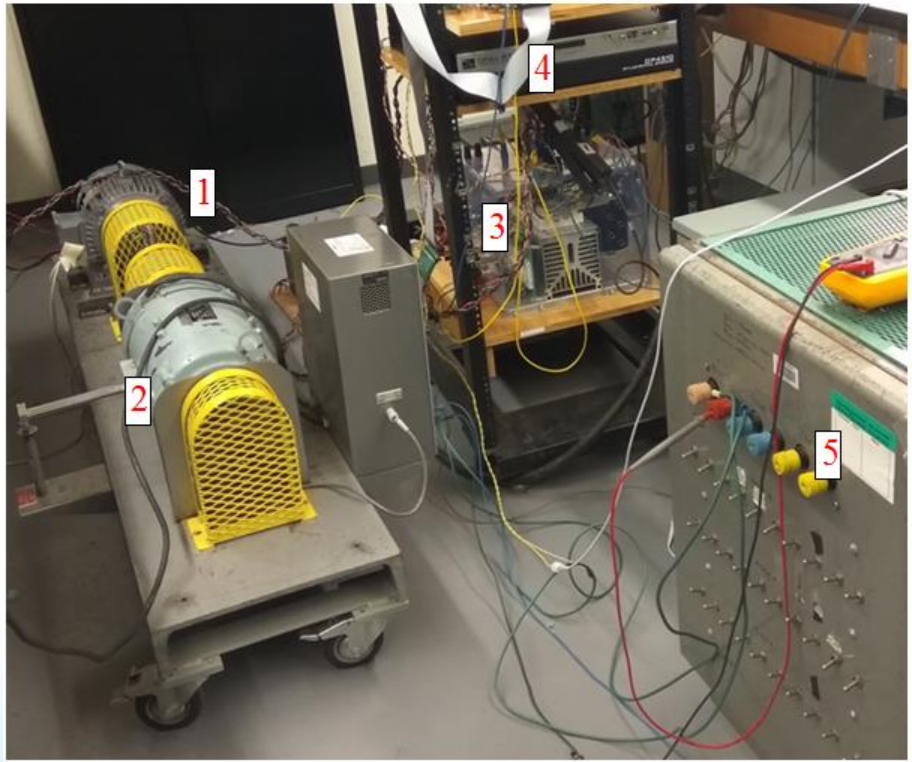
Power amplifier- linear

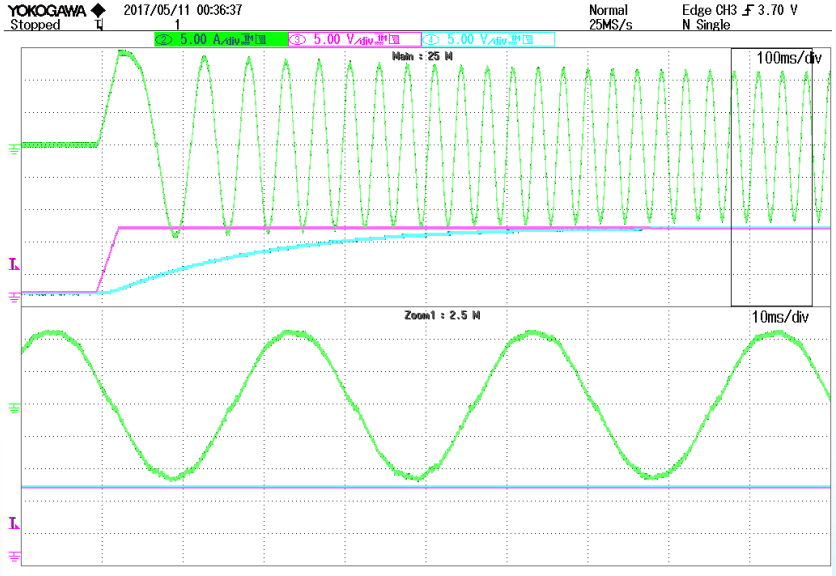
- 1 amplifier per phase – AETechron 7548
- 3.3 kW sourcing and 1.2 kW sinking power per phase; bandwidth DC-40 kHz - ±180 Vpk
- Possibility to operate in both current control and voltage control mode
- Amplifiers operated in software current control mode with modeled machine current acting as reference

Results with a physical PMSM drive

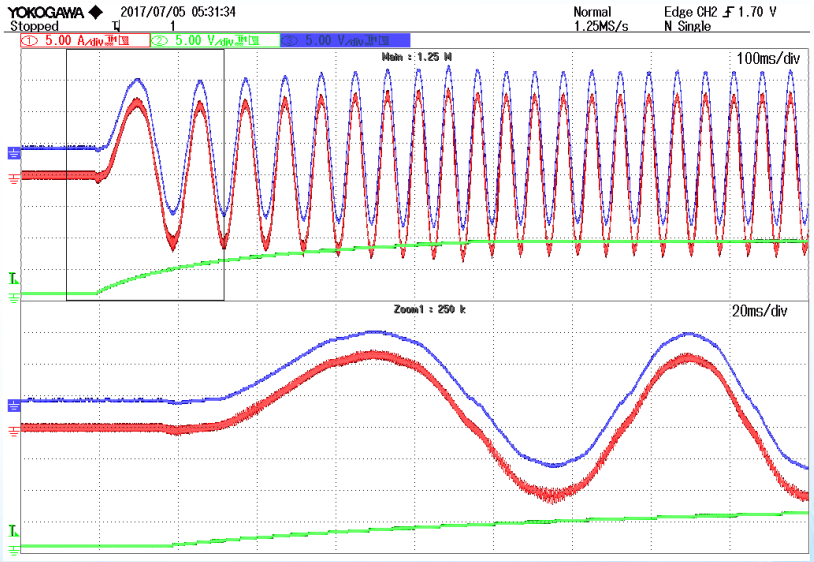


- Experimental setup consists of a physical surface-mounted PMSM coupled to a DC dynamometer
- A simple vector control algorithm used for controlling the PMSM

Dynamometer/ emulator comparison



Dynamo-meter



Machine emulator

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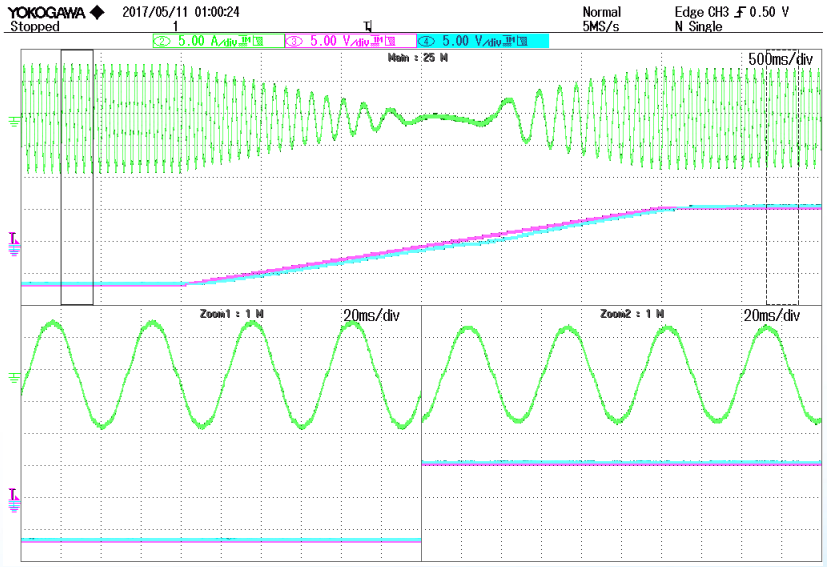
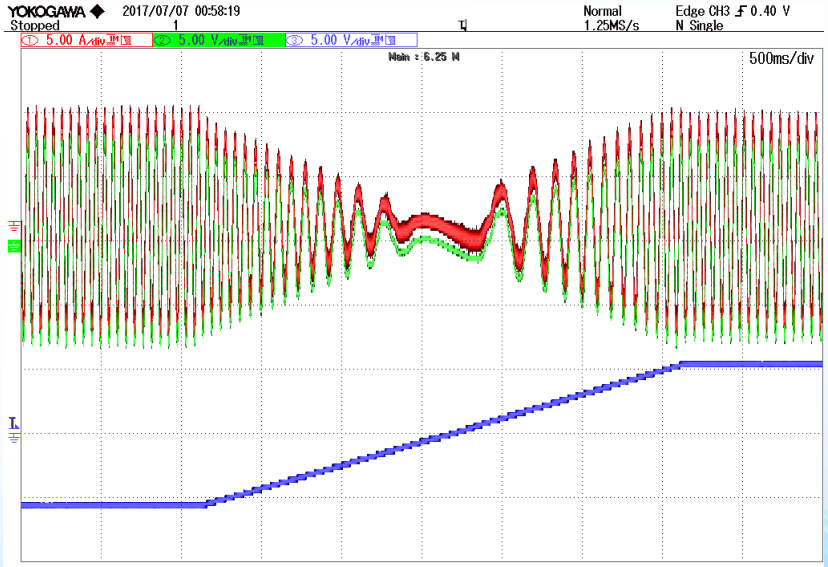
Dynamometer/ emulator comparison



Dynamo-meter



Machine emulator

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Summary

- Design files of a surface mounted PMSM from MotorSolve used to generate flux and torque tables for OPAL-RT PMSM models
- Experimental setup being developed for a 4-quadrant 6-switch power amplifier and a linear amplifier to perform power-hardware-in-loop machine emulation
  - Results obtained being compared with a physical experimental dynamo-meter
- Once developed completely the machine emulator system can also be used to validate other machine modes

Acknowledgement

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THANK YOU

Questions???

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