DOE/OE Transmission Reliability Program

Field Characterization of Rotating and Electronically-Coupled Machine Parameters

Birth of an automated learning system

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Topics to Address

- **Overall project objective**
- **Looking Back:**
  - Major accomplishments during the past year (July 2013-June 2014, since the last review meeting)
- **Looking Forward:**
  - Major technical accomplishments that will be completed in FY14—current stage in RD&D cycle
  - Deliverables and schedule for activities to be completed under FY14 funding
  - Risk factors affecting timely completion of planned activities as well as movement through RD&D cycle
  - Early thoughts on follow-on work that should be considered for FY15 and beyond

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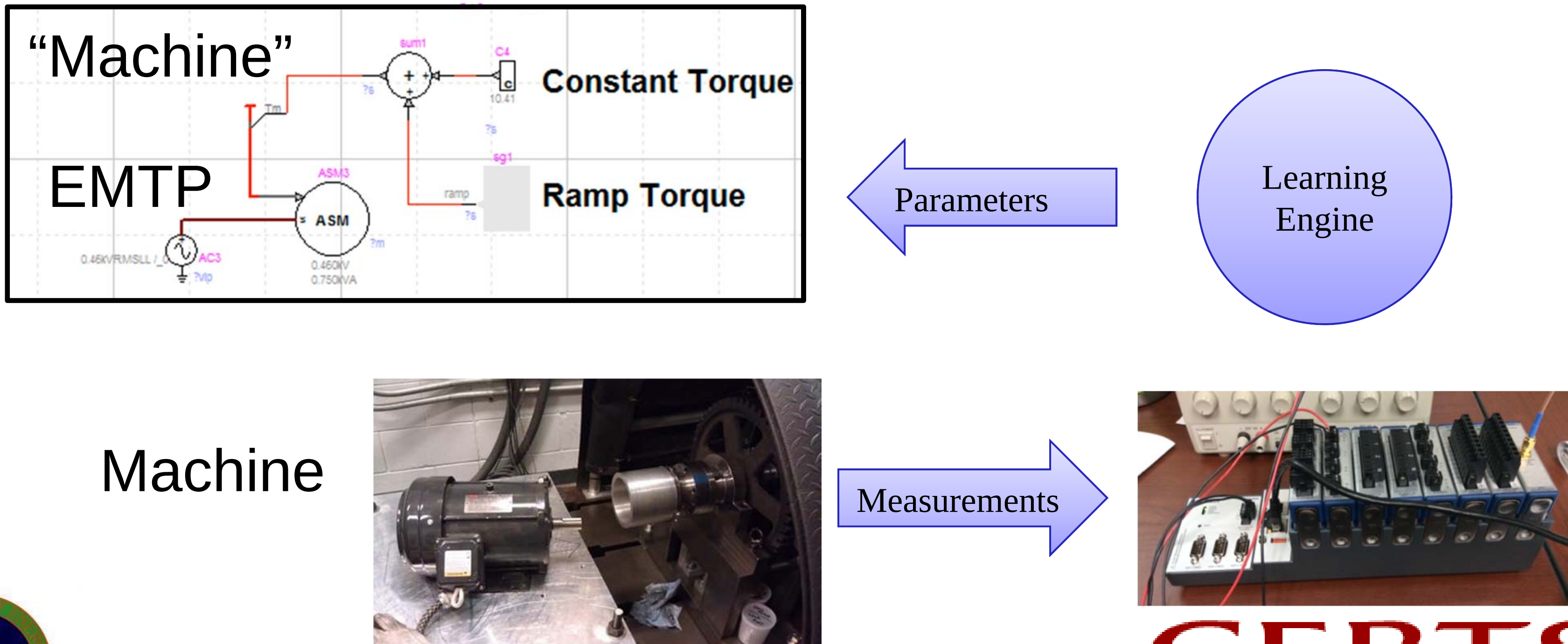
FY14 Project Objective

Learn from empirical data the model parameters of selected rotating and electronically-coupled equipment to faithfully represent steady state and **dynamic** behavior



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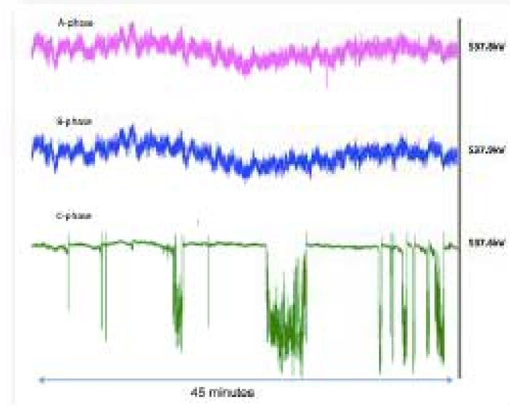
Motivation

- Develop an adaptive, on-line learning system
  - Faithful representation of the components in system
  - Track changes to component behavior
  - Correlate changes to system health
- Determine what additional value can be derived from the existing fleet of PMU’s
  - “How fast is fast enough?”
  - Identify the shortfall (if any) in the existing PMU fleet
- Provide a data-driven basis for future investments
- Enable on-line asset monitoring, assessment and condition based maintenance

CCVT Failure

•PMU captured this CCVT failure at instant it began

•Failure apparent 4-days before the relay/SCADA alarm

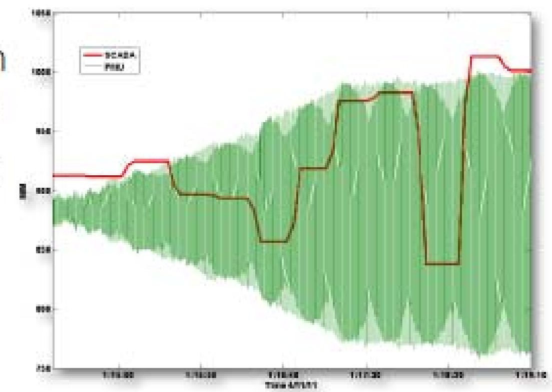


Generator Oscillation

•Large generator oscillation of +/- 200 MW

•Not detected by traditional SCADA data

•Had impact on 6 other generating stations



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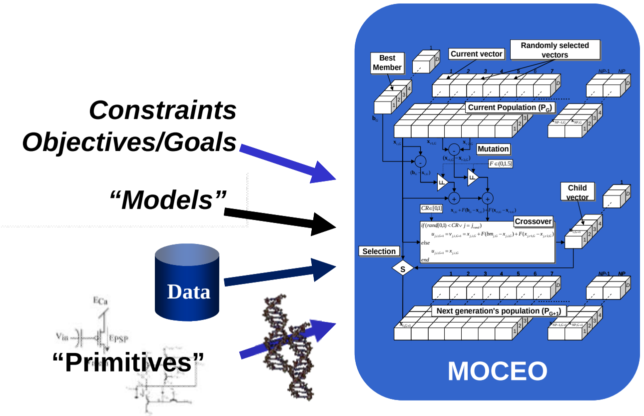
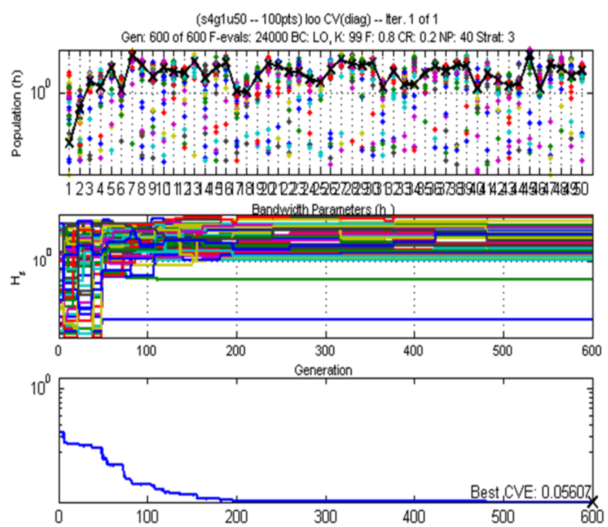
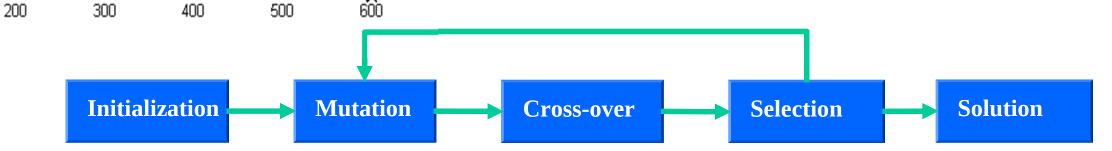
*Dominion’s Synchrophasor Design and Deployment - Presented by: Kyle Thomas
DOE Project Review, Dominion Virginia Power/Virginia Tech Project, Richmond, VA 19 Aug 2013

Learning System: Multi-Objective Constrained Evolutionary Optimization Using Differential Evolution





- Differential Evolution (DE) is a population-based, direct search, evolutionary optimization algorithm
- Similar to other population based search algorithms
  - –Genetic Algorithms
  - –Evolutionary Strategies
- Different
  - –Self-referential mutation scheme
    - Based on vector differentials
    - Step size varies w/ time & is a function of the std dev of parameters in the population
  - –Cross-over (more mathematical, PDF-blending)
  - –Selection (child or parent)



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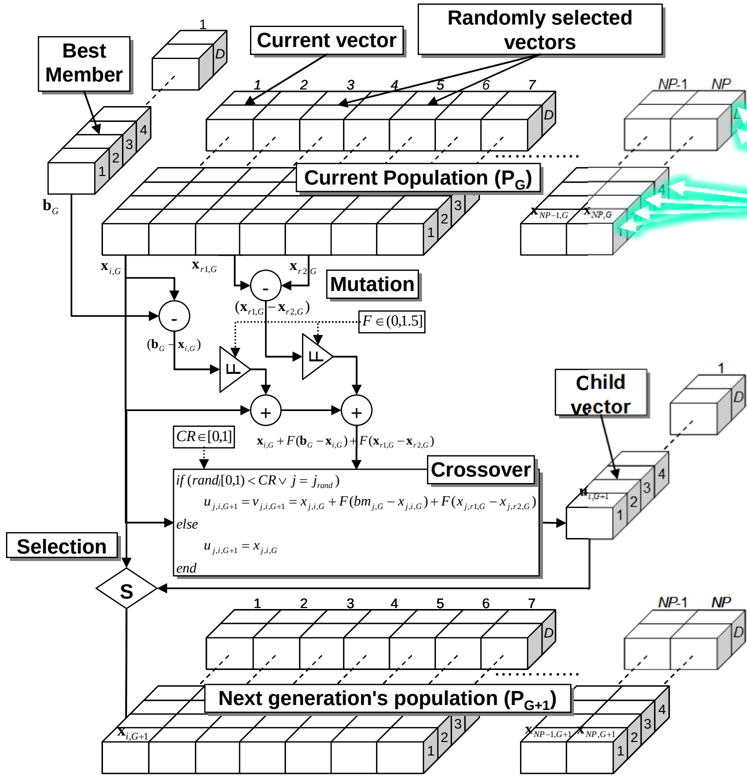
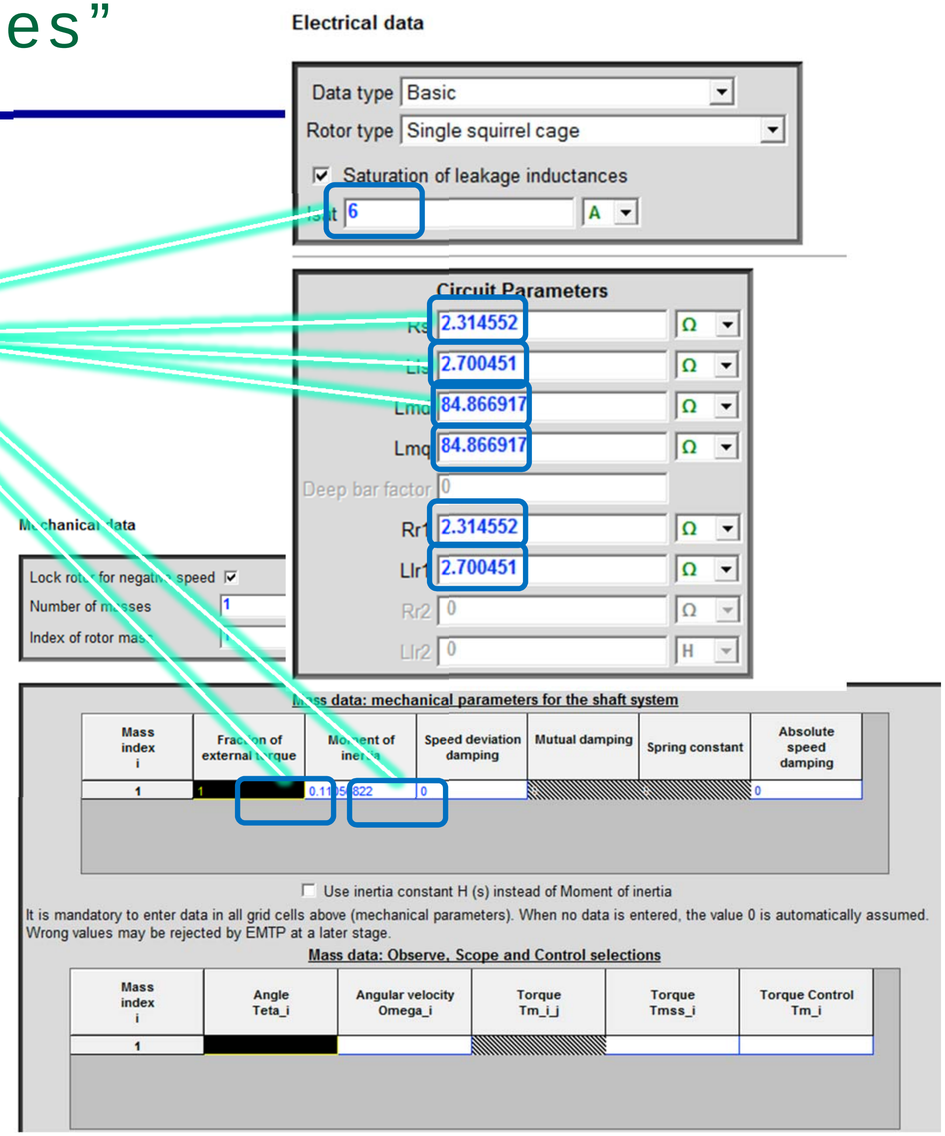
Mapping model parameters to population vectors or “chromosomes”

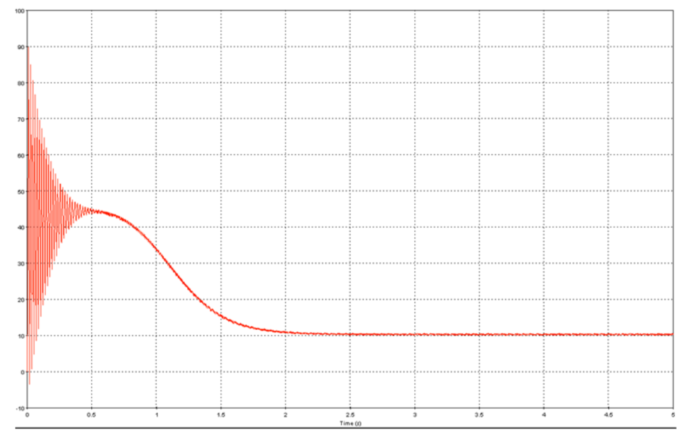


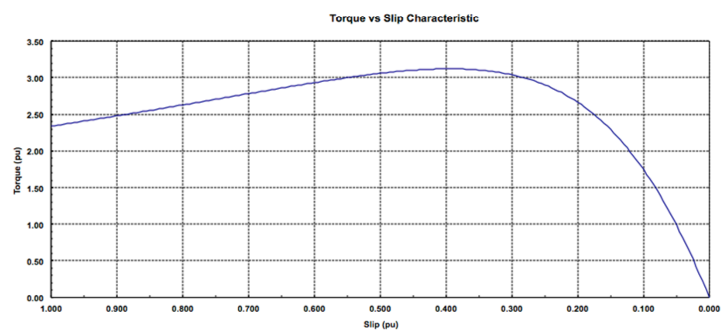


- Complete motor model is simulated in EMPT
- Model parameters are mapped as a “chromosomes”
- Initialized population can include best known design
- Objective
  - Minimize Error between simulation output and measured data over all conditions

Accomplishments

- Configured *"PMU"* equipment to provide high sample rate (50 ksps) measurements
  - Can decimate to any desired PMU rate
- Developed and executed test plan
- Developed initial EMTP model of the device based on nameplate
- Simulated the device under varying load conditions
- Operated device under varying load conditions
- Started data collection





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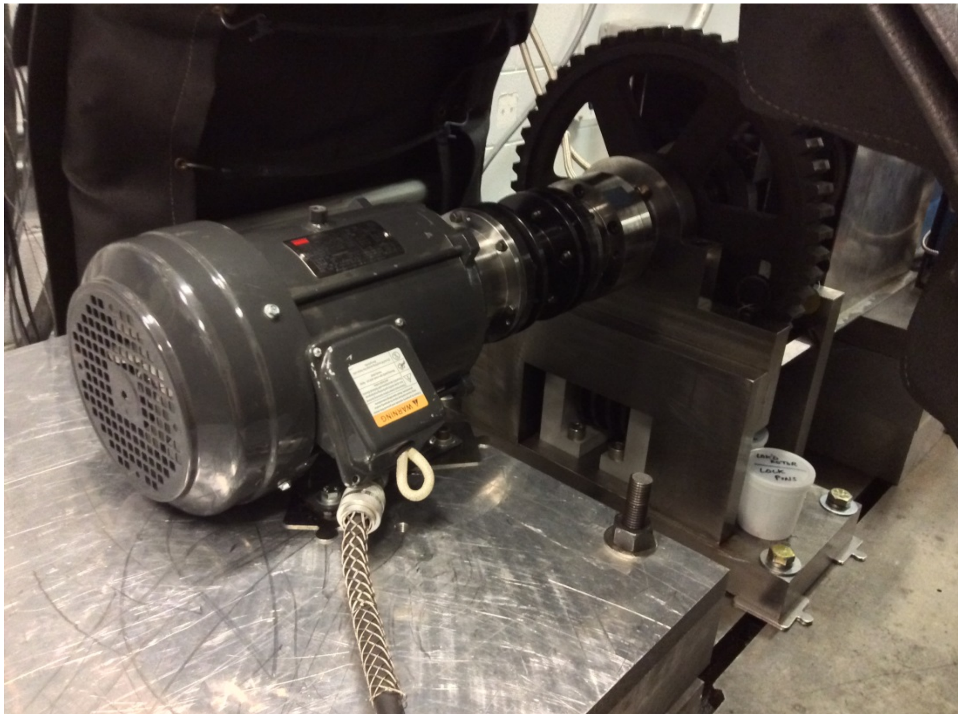
Dyne Setup



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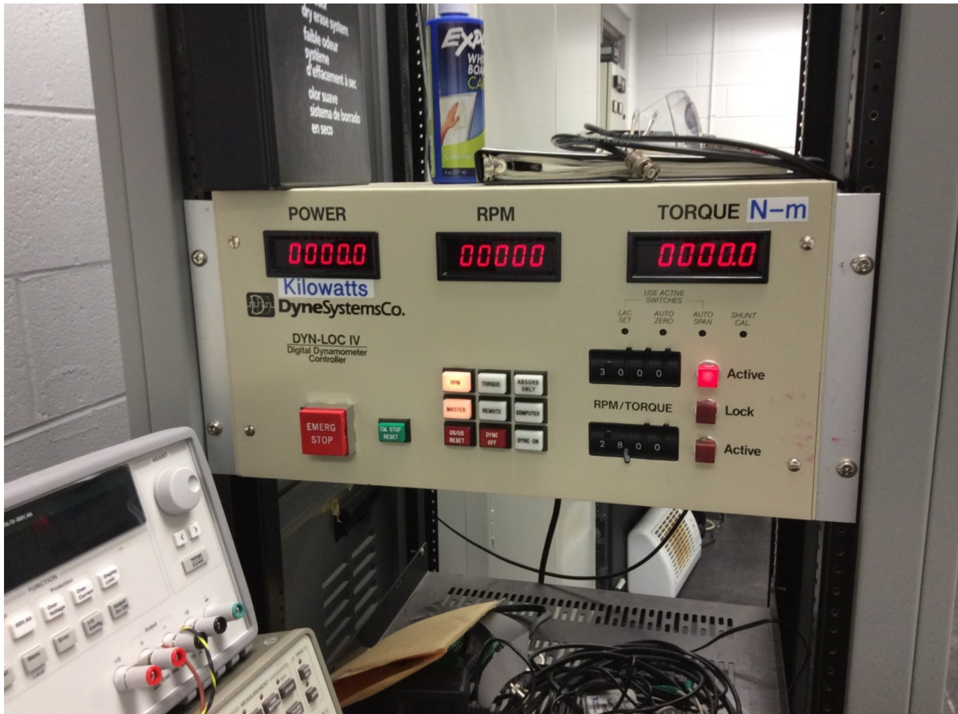
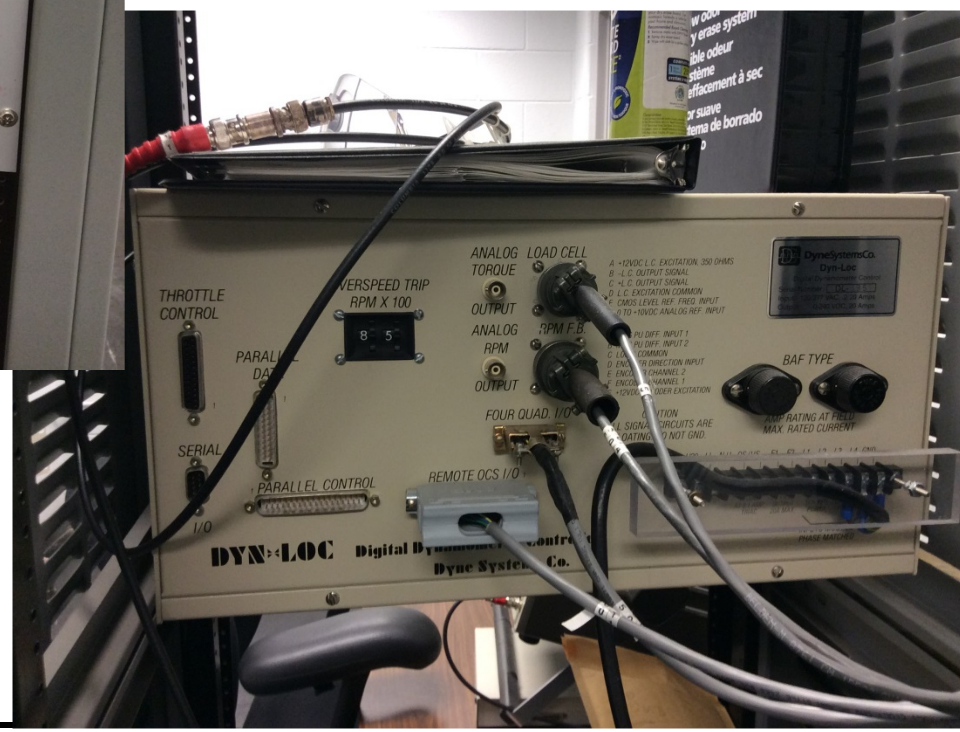
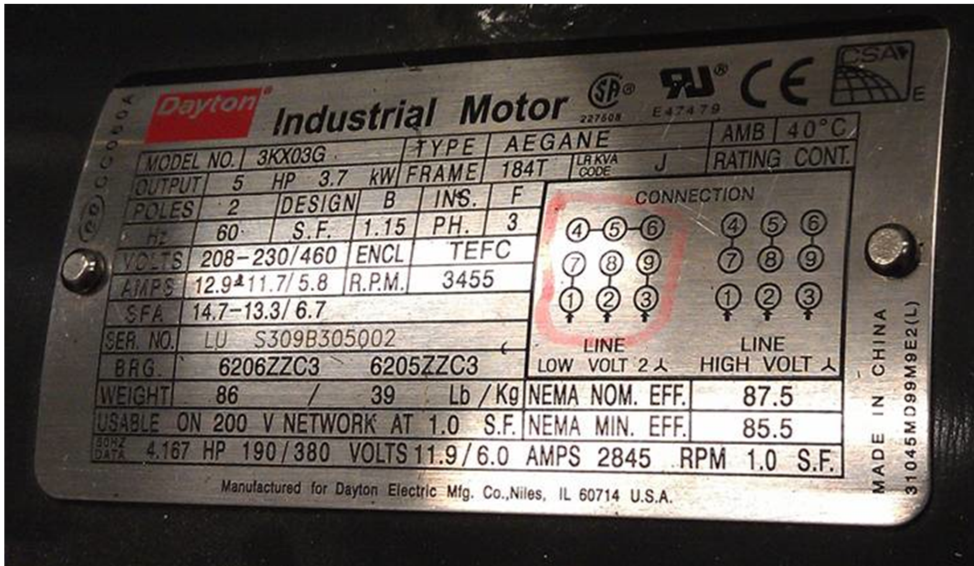
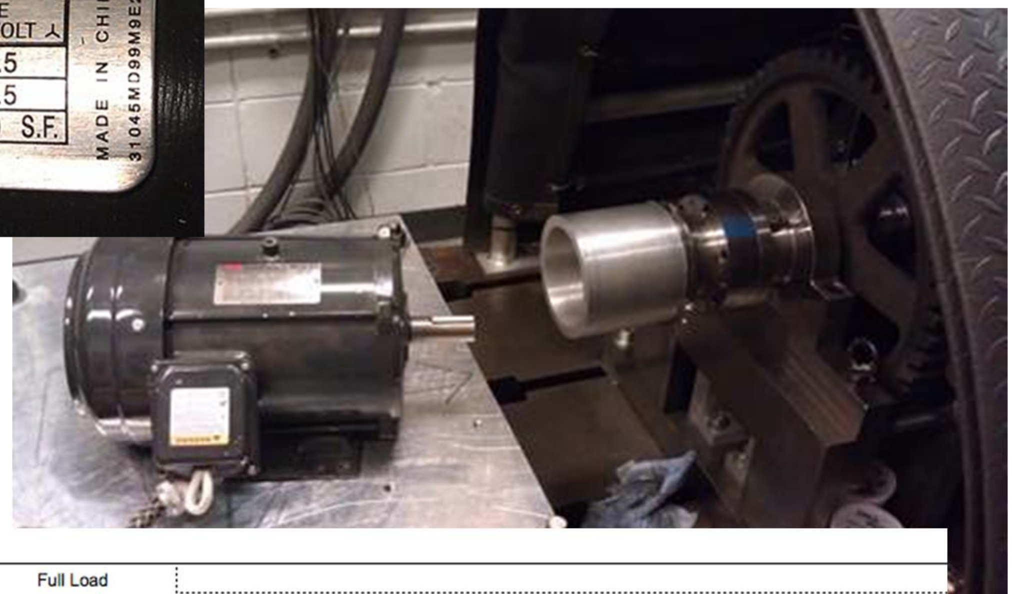
DyneSystems Control





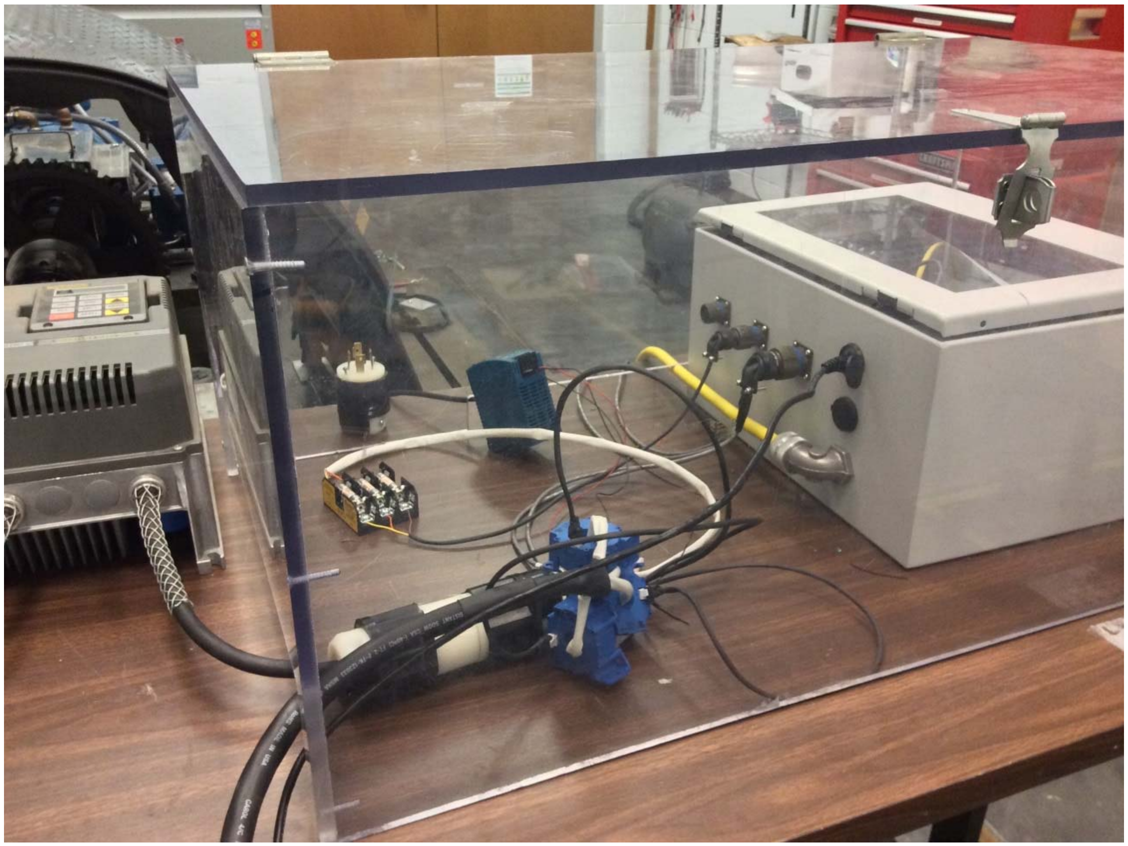




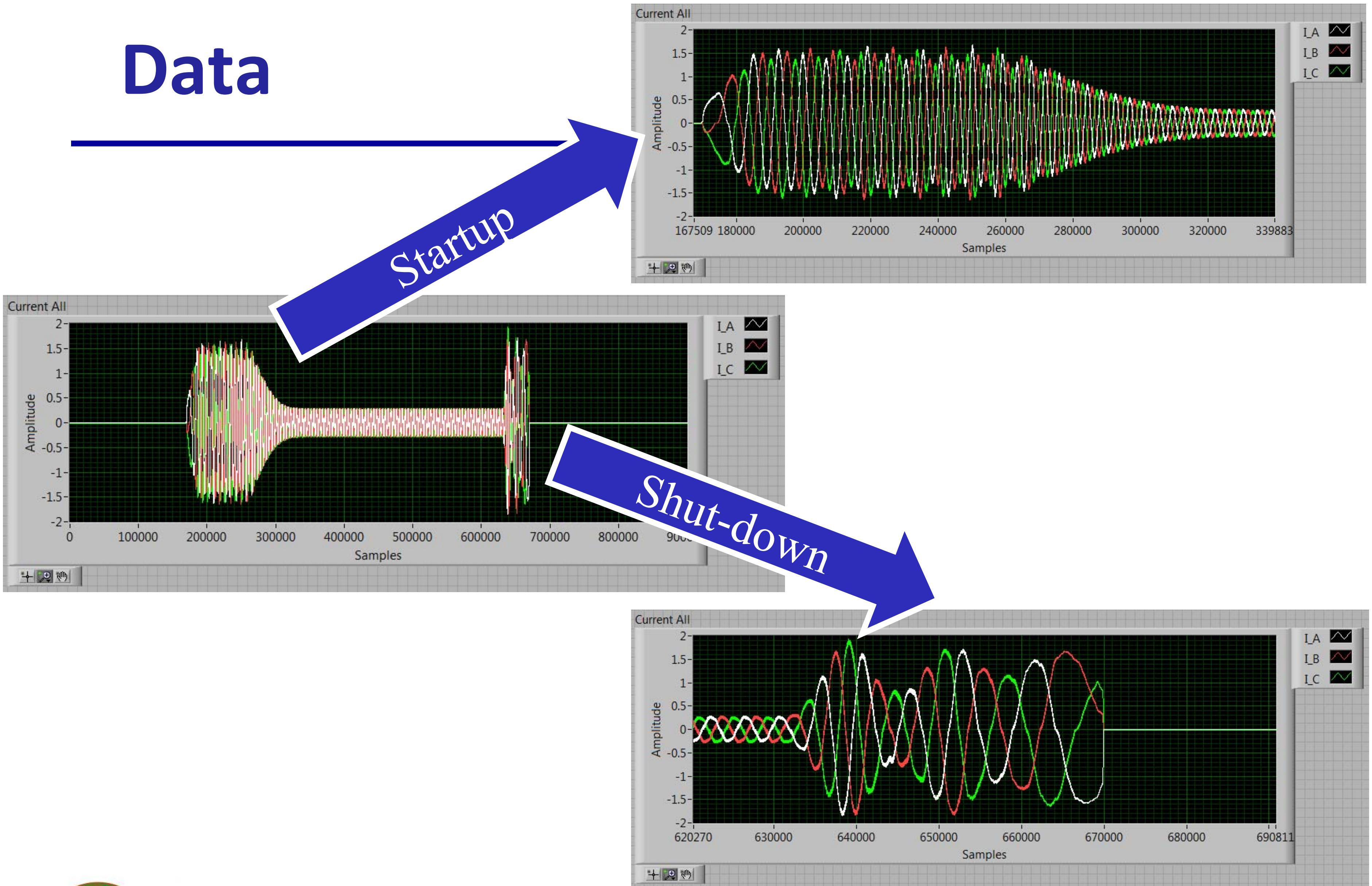
Typical Data:

Rating (HP)	Full Load Efficiency (%)	Full Load Power Factor (%)	Full Load Slip (%)	Xs+Xr (pu)	Xm (pu)	Rs (pu)	Rr (pu)
<5	75-80	75-85	3.0-5.0	0.10-0.14	1.6-2.2	0.040-0.06	0.040-0.06
5-25	80-88	82-90	2.5-4.0	0.12-0.16	2.0-2.8	0.035-0.05	0.035-0.05
25-200	86-92	84-91	2.0-3.0	0.15-0.17	2.2-3.2	0.030-0.04	0.030-0.04
200-1000	91-93	85-92	1.5-2.5	0.15-0.17	2.4-3.6	0.025-0.03	0.020-0.03
>1000	93-94	88-93	1.0	0.15-0.17	2.6-4.0	0.015-0.02	0.015-0.025

Data Acquisition



Data


Startup
Shut-down
Current All
I_A
I_B
I_C
Amplitude
Samples
Current All
Current All

Looking Forward (FY14)

- Operate device under varying load conditions
- Collect data for varying load conditions
- Learn model parameters off-line…
  - Deliverable: summary report
- Implement real-time model simulation using LabVIEW/Multisim/FPGA
  - Deliverable: summary report
- Develop and implement automated on-line learning system
  - Deliverable: summary report

Milestones

- April 2014: EMTP model ("machine")
- June 2014: Machine characterization platform
- Jul. 2014: Machine characterized
- Sept. 2014: Off-Line Learning System
- Oct. 2014: Real-time machine simulation (LabVIEW/Multisim)
- Dec. 2014: Automated On-line Learning System

Risk Factors

- Availability/Access to motor test facility and dynamometer
- Adaptation of the Learning system from batch-mode to online/real-time
- Integration/automation of dynamometer, data collection, model/simulation, and optimization.

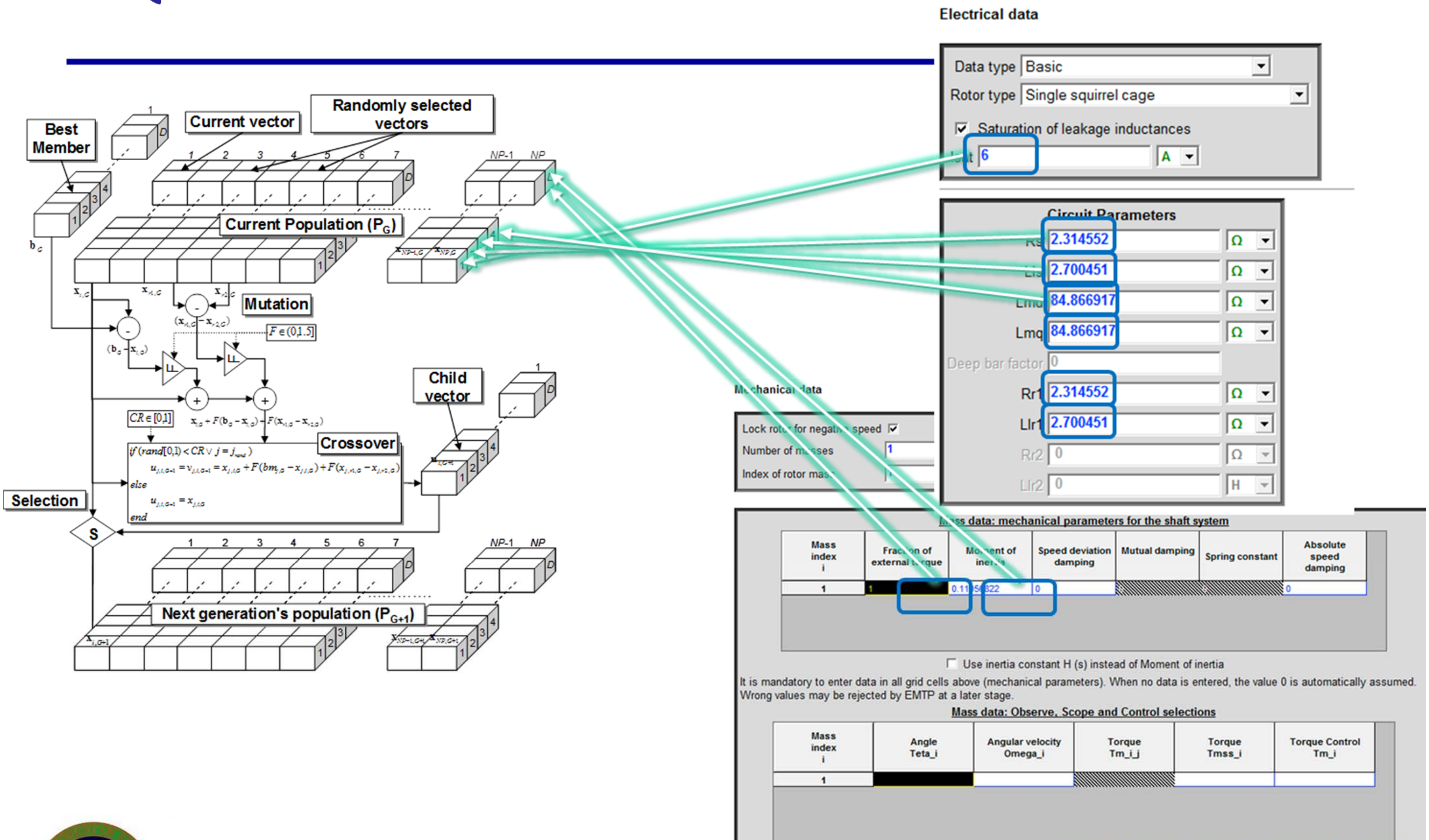
Future work FY15

- Adapt learning system for electronically coupled devices
  - Characterize an inverter using the machine as the dynamic source/load
  - Develop and simulate real-time inverter model in LabVIEW/Multisim/FPGA
  - Develop and implement automated on-line learning system

Future work …

- Create an “Oracle” – “Intelligent Historian”
  - Identify phenomena of interest
  - Determine appropriate sample rates and algorithms
  - Identify the shortfall (if any) in the existing PMU fleet
  - Prototype “Oracle”
- Transition “Oracle” to the field
  - Identify utility/industry partner
  - Collect field data
  - Characterize phenomena of interest
  - Develop Initial Condition-Based Maintenance Algorithms

Q&A



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