Composite Load Model Testing

Testing done by

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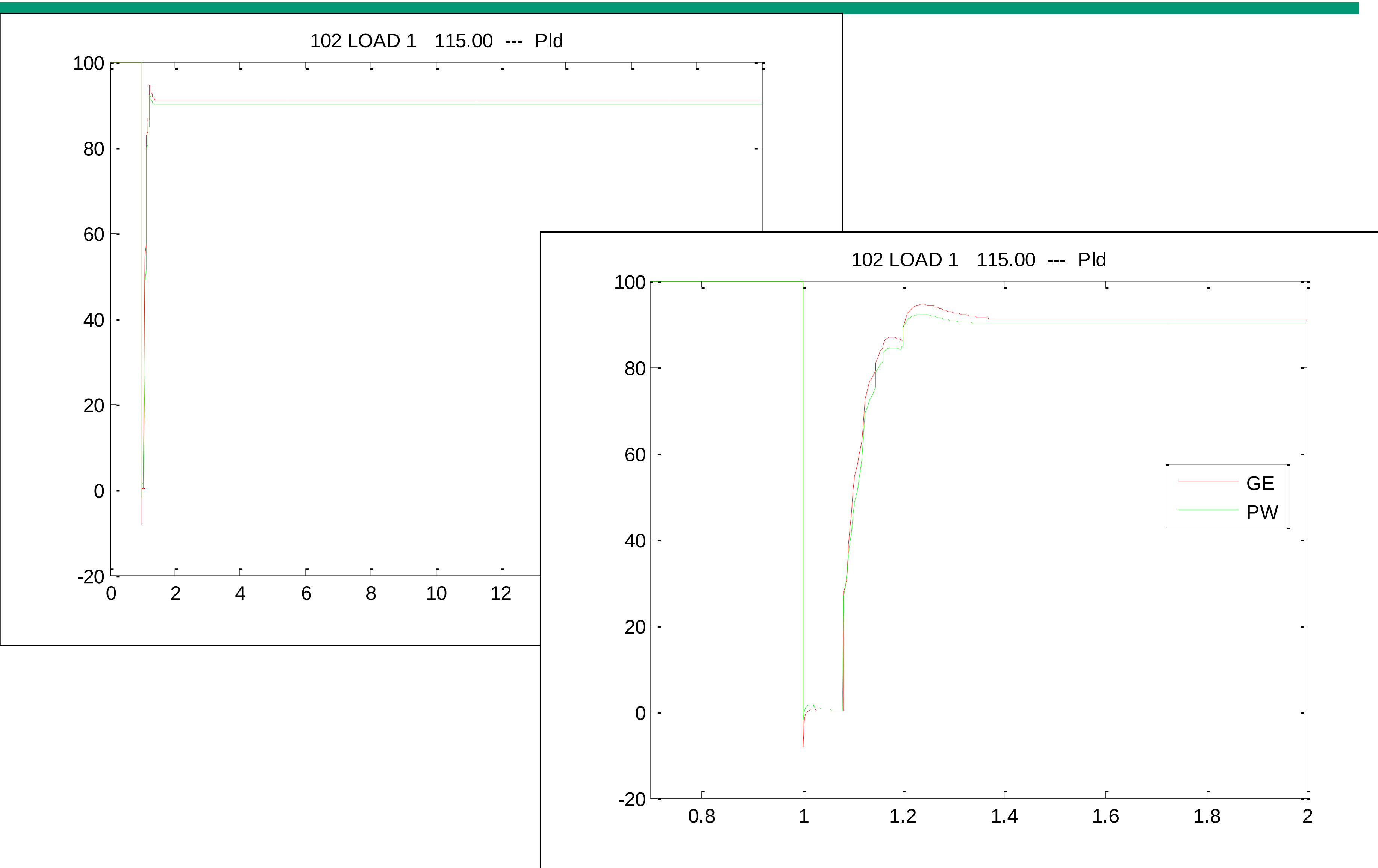
Tom Overbye and Komal Shetye at the University of Illinois
Song Wang at PacifiCorp (did PSSE runs for comparison)

October 2014

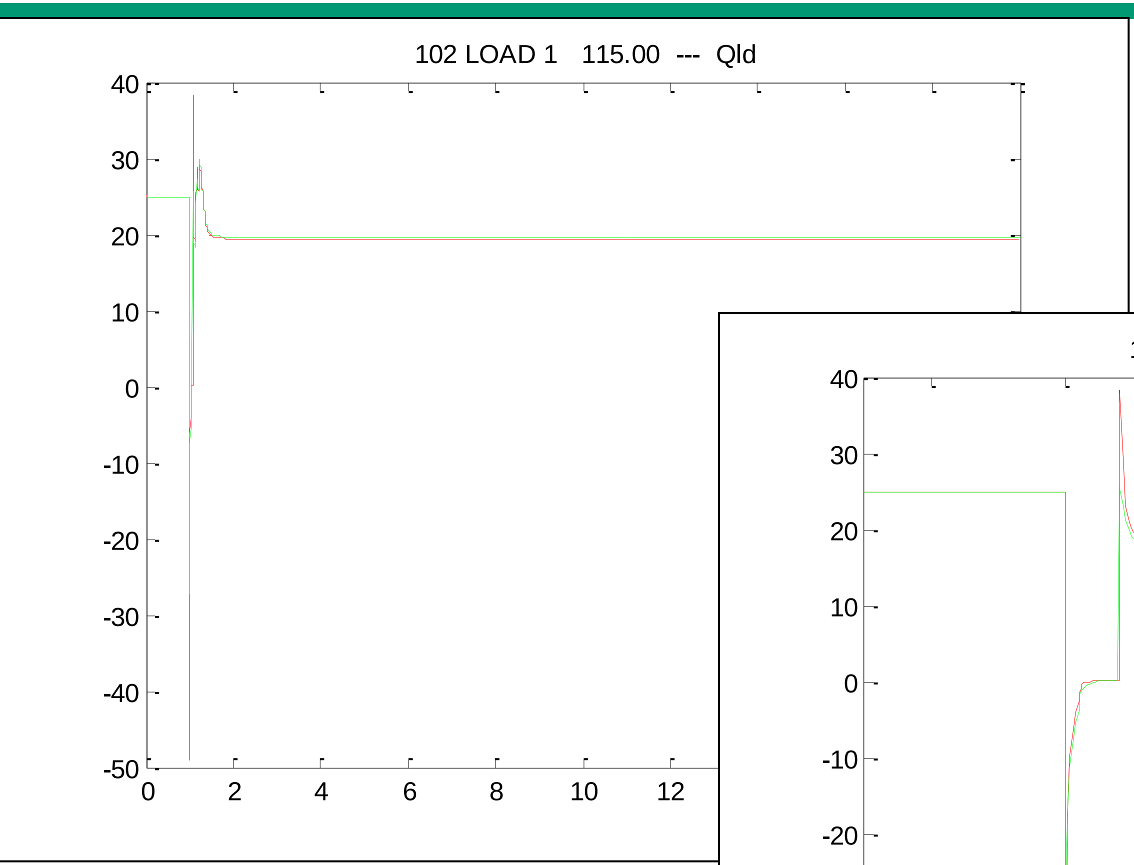
Benchmarking of CMPLDW

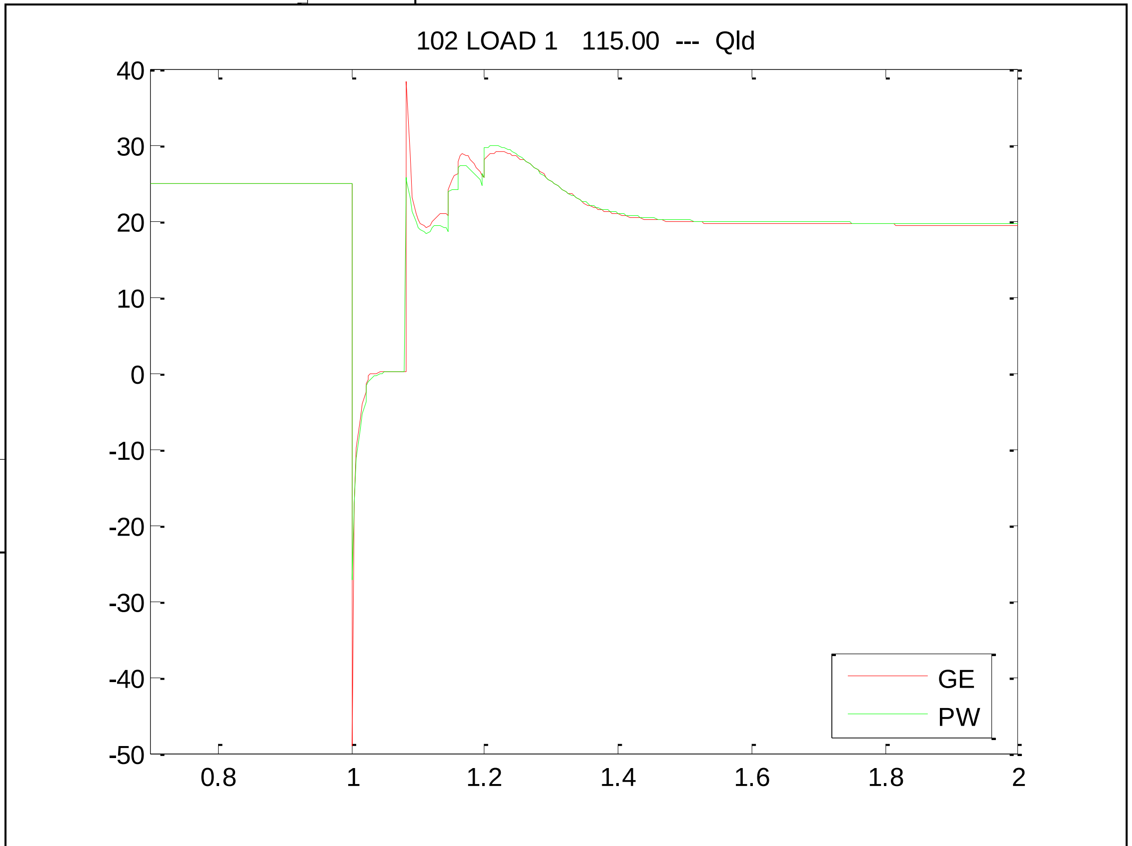
- Testing both "Phase 1" and "Phase 2" CMPLDW models
  - "Phase 1" means the CMPLDW without including the single-phase air-conditioner model
  - "Phase 2" means it includes the single-phase air-conditioner model with stalling
- This work focused on testing results in GE PSLF and PowerWorld Simulator
  - Results show they have largely the same response
- Small amount of work was done with PSSE results as well (Frequency results and Torques)

CMPLDW Total Load P with air-conditioner

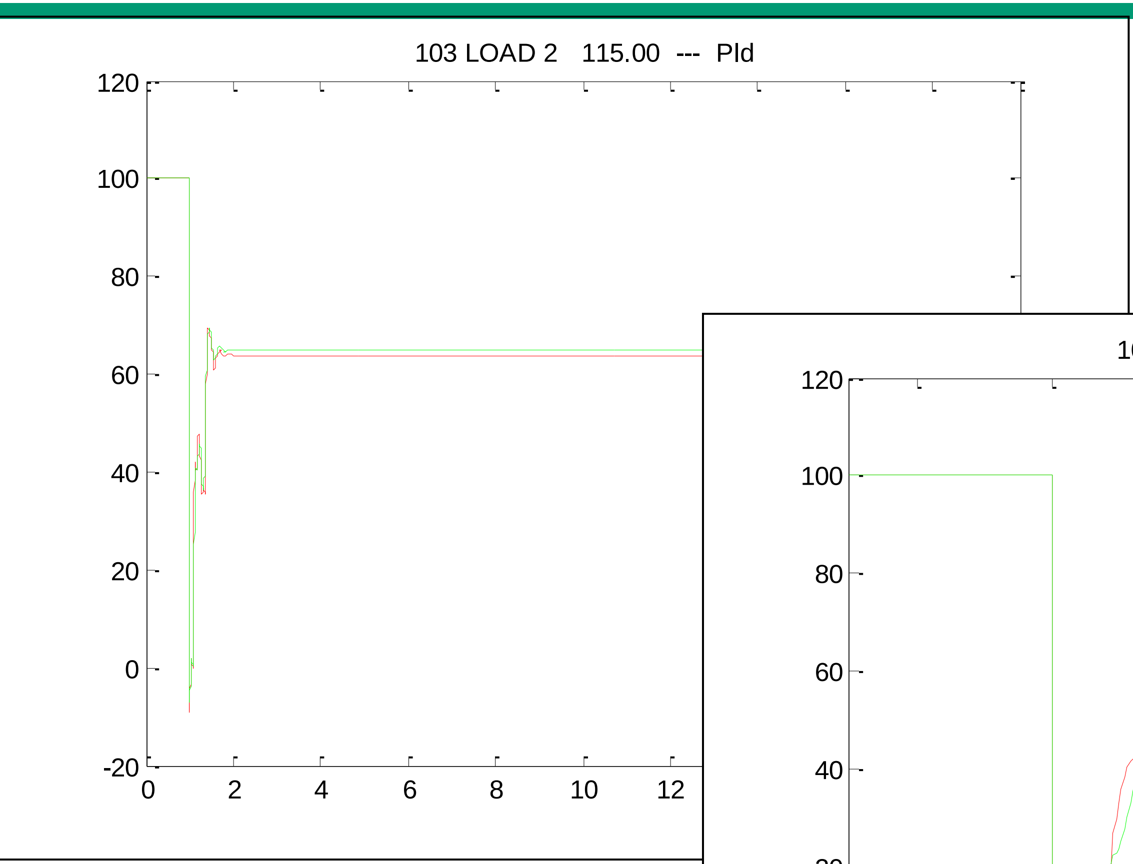


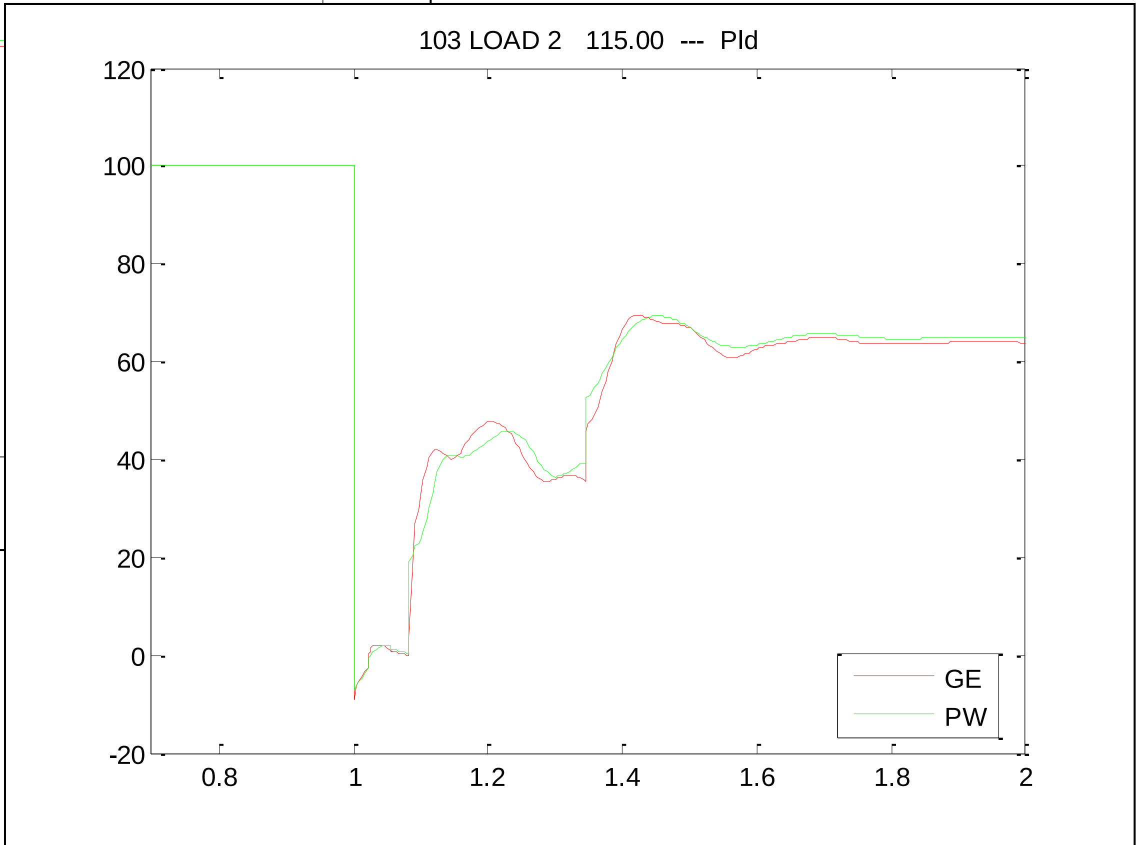
CMPLDW Total Load Q with air-conditioner



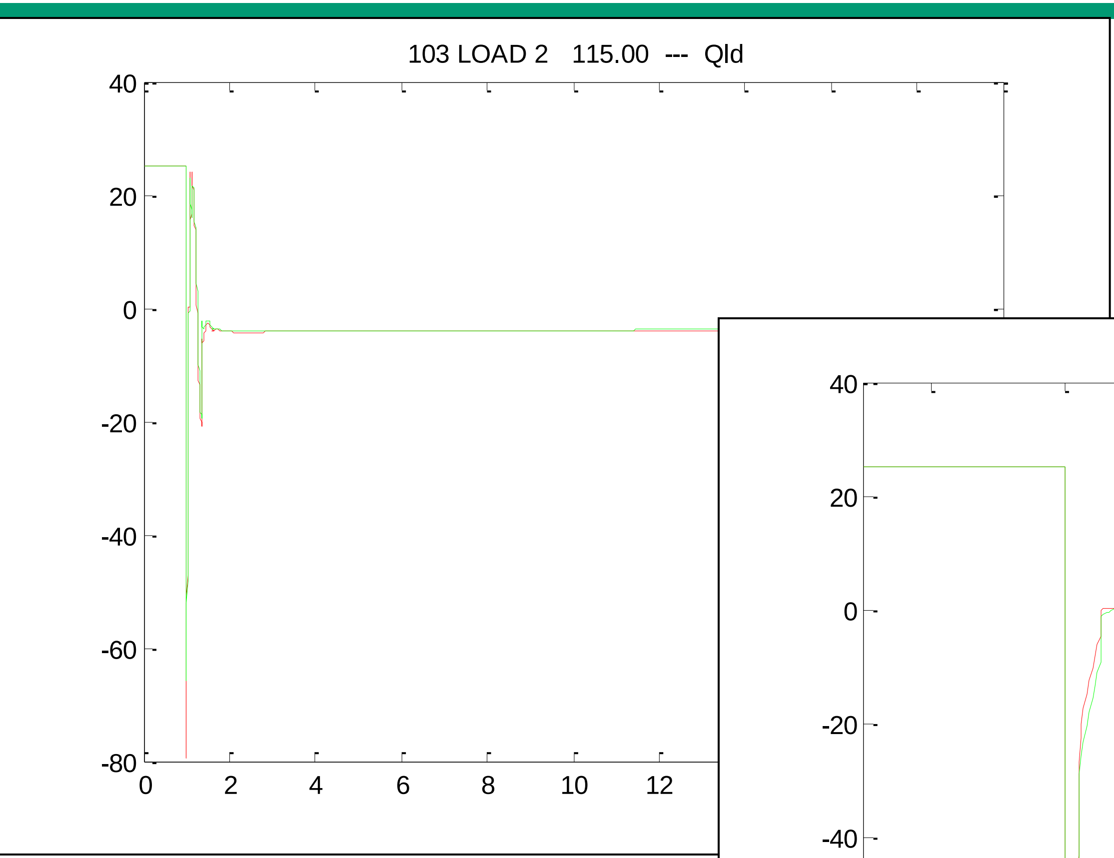


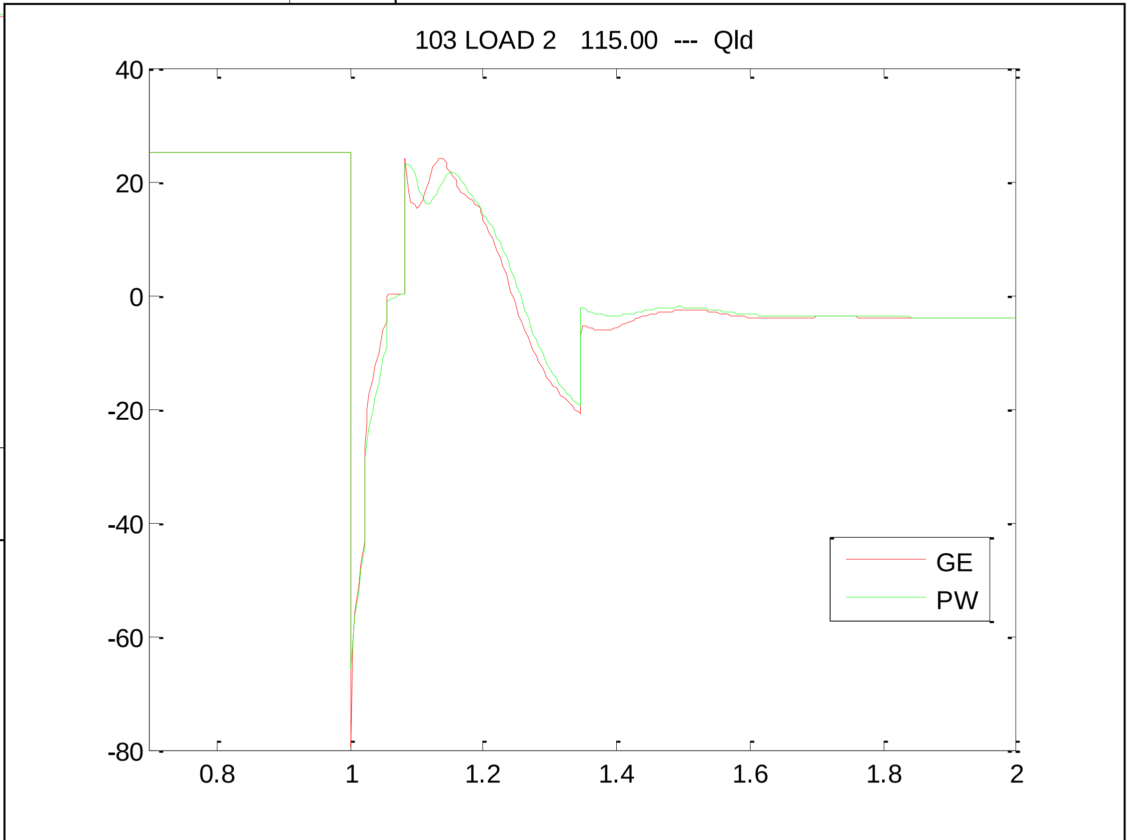
CMPLDW Total Load P without air-conditioner





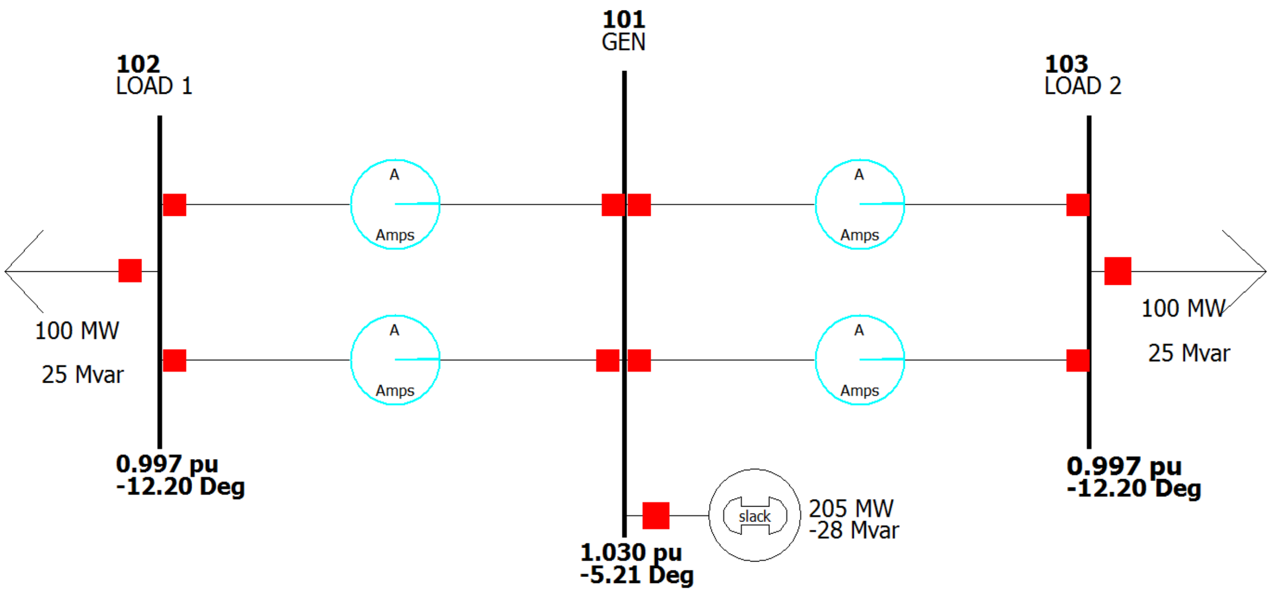
CMPLDW Total Load Q without air-conditioner





Test Simulation

- Three phase fault at bus 101 for 5 cycles (0.083333 seconds).
- Clear fault by opening one of each

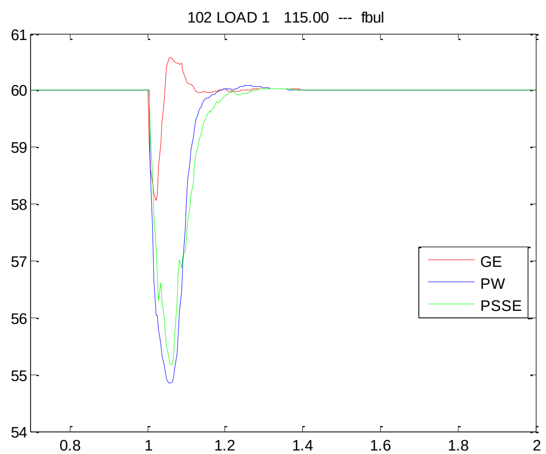


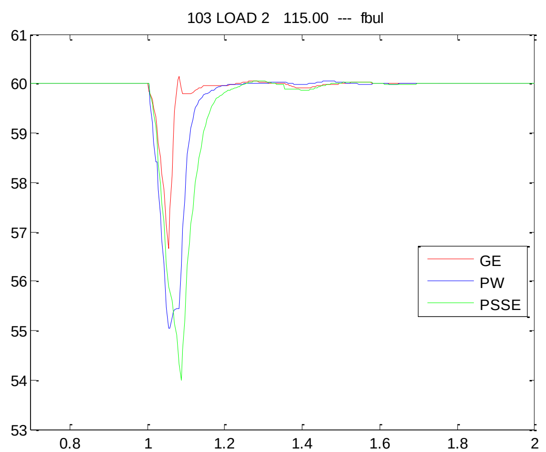
Findings

- Software Settings and Result Reporting Differences can cause confusion
- Communicated with PowerWorld staff and got some bugs fixed
- Have some open questions about appropriate way to model motors

Fault Impedance Might Matter

- Initial Frequency Results
  - PSLF was different. Frequency dip only to 58 Hz instead of 55 Hz

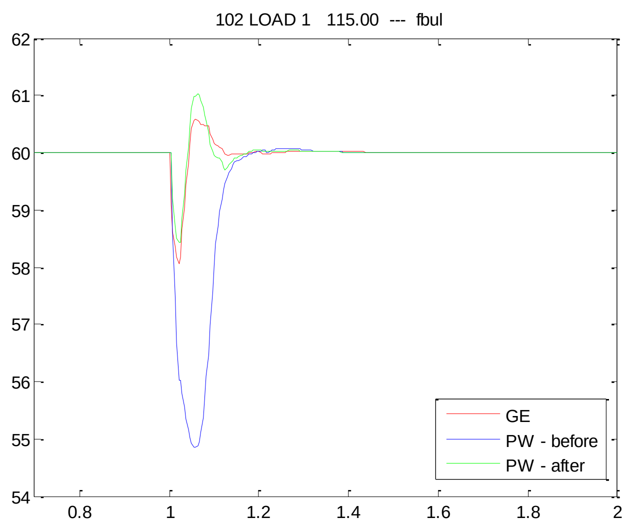


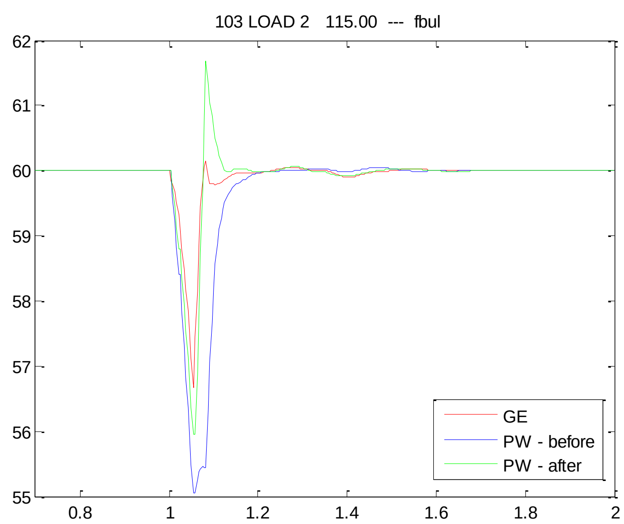


- Solely due to the default fault impedance

Fault Impedance Might Matter

- PowerWorld staff let us know that for a "solid" fault, a fault reactance of 1E-8 is used
  - When fault reactance set to 1E-5, results match those of PSLF –presumably that's what is used





Why does fault impedance matter

- Artifact of this example case
  - Generator internal impedance Xdpp = 0.2 per unit, but MVABase = 125,000 MVA
  - On a system MVABase, that means
    - Xdpp(System) = 0.2 * 100/125000 = 1.6E-4
    - 1.6E-4 about the same order as the 1E-5 fault impedance, thus this fault impedance is too big for this particular example
  - In a real WECC case, this is not a concern, but can be on these little simple test cases.
- For remainder of testing a fault impedance of 1E-5 was inserted into PowerWorld contingency

Variation of Fault Impedance

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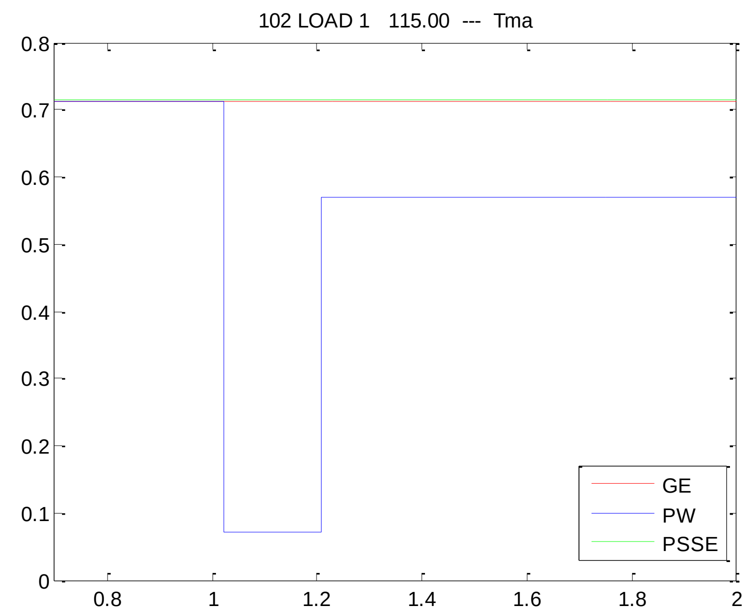
CMPLDW Motor Tripping

- For induction motors, CMPLDW allows "50% of motor to trip"
  - For a real motor, this makes no sense
  - CMPLDW is meant to model 100s or 1000s of motors though
  - This just means that half of them trip
- How does CMPLDW model motors
  - Models equations of only **ONE** motor
  - Then adds a scalar multiplier on the network boundary equations to scale the percentage of the load seen by the network
  - Essentially you can think of it as a variable "MVABase"
  - Question: How should we report motor torque?

How to report Motor Torque? Per Unit or MWs

- Prior to July 15, 2014 PowerWorld would report torque in per unit based on the initial MVABase.
- Thus as percentage of motors were tripped, the torque would move
- PSSE and PSLF reported the internal torque of equations without the scalar



- All these simulations are correct
  - This is solely a reporting issue

Changes to Simulator help with reporting

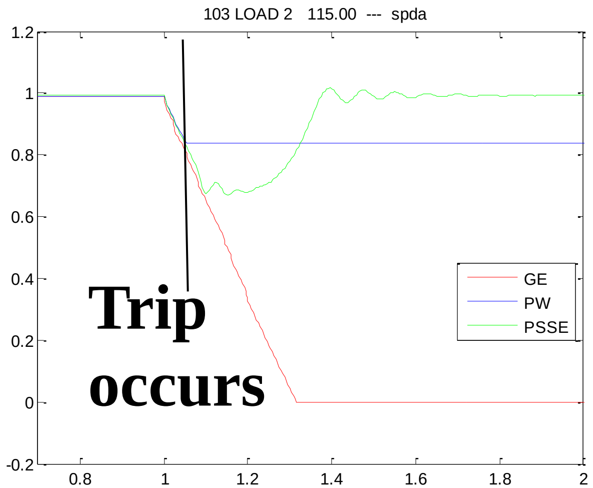
- Starting July 16, 2014, PowerWorld Simulator reports values scaled to MWs
- PowerWorld added extra "other fields" for the CMPLDW model to report for each motor (A, B, C, D)
  - Fraction not Tripped on Undervoltage
  - Present MVABase of motor
    - To get per unit then just take the MW values and divide by MVABase

$$T(pu) = T(MW) / MVABase$$

Report

Speed Reporting after 100% Tripped

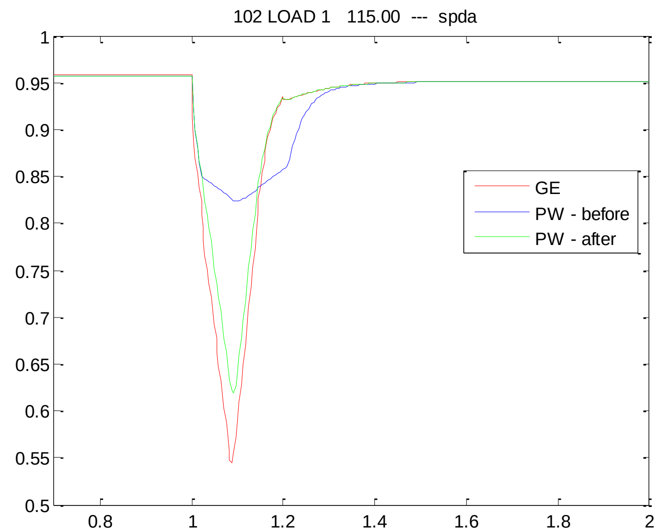
- CMPLDW allows motors to "reconnect" after they trip
  - This is just changing the scalar multiplier talked about on last slides
  - However, CMPLDW specifies that after 100% of the motor has tripped then it may NOT reconnect
    - PowerWorld Simulator simply quits integrating the equations associated with any out-of-service element which can not be reconnected
    - It truly doesn't matter at all



Bug Fix

Bug Fixes: Motor Speed for percentage trip

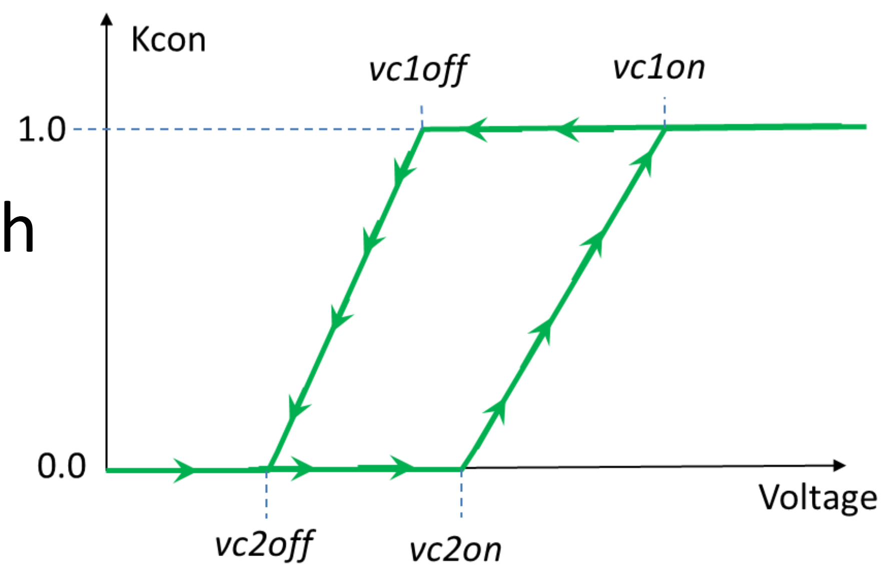
- MOTORW allows under-voltage tripping, but only 100% tripping is permitted
- CMPLDW allows you to trip a percentage of the motor as we've discussed
- There was a bug when a percentage of the motor was tripped in the motor speed derivative calculation
  - Fixed in patch on Sept 19, 2014
  - A related bug existed when 100% of load was tripped as well which was fixed in Sept 23, 2014 patch



Bug Fix

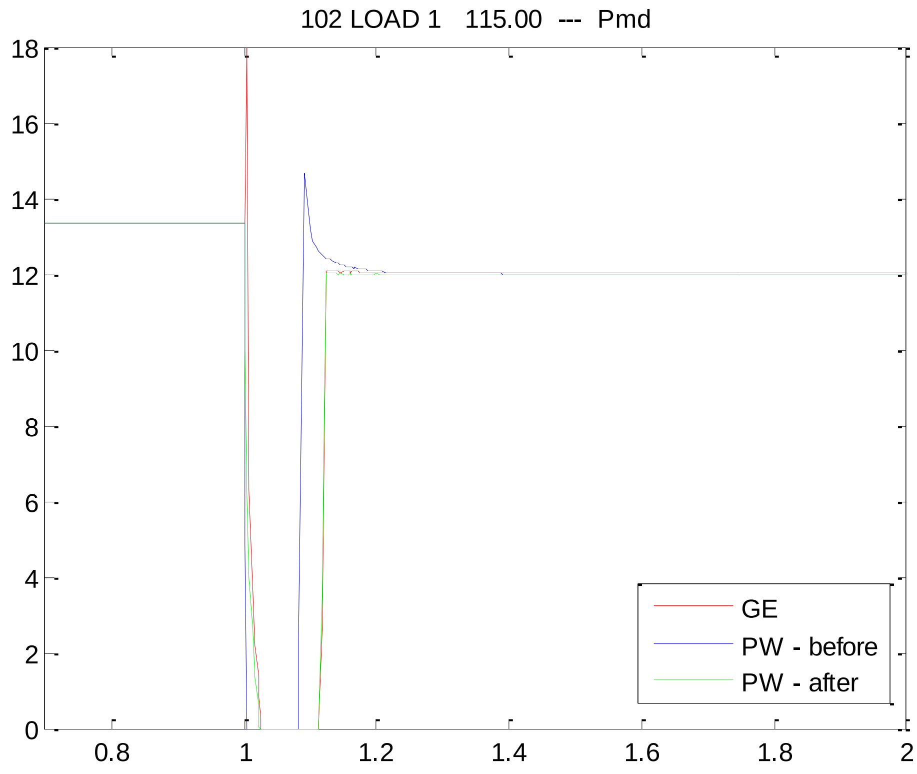
Single-Phase Air-Conditioner Tvd delay on Contactor

- Contactor Model
  - The x-axis should be AFTER the measurement delay specified by Tvd
  - PowerWorld Simulator was not properly using that delay
  - This has been fixed in the Sept 19, 2014 patch



Bug Fixed in using measured voltage in contactor model

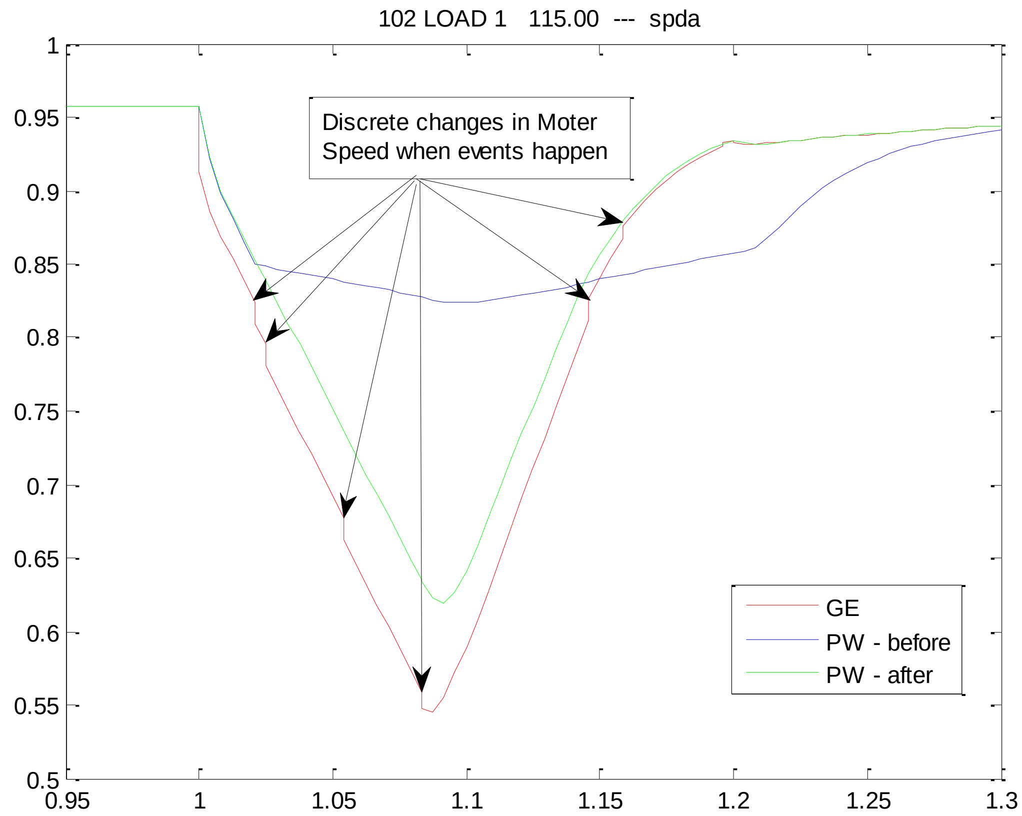
- Tvd = 0.025 in sample case
- See delay in green and red lines recovering equation to 0.025 seconds



Open Question

Discrete Changes in Induction Motor Speed

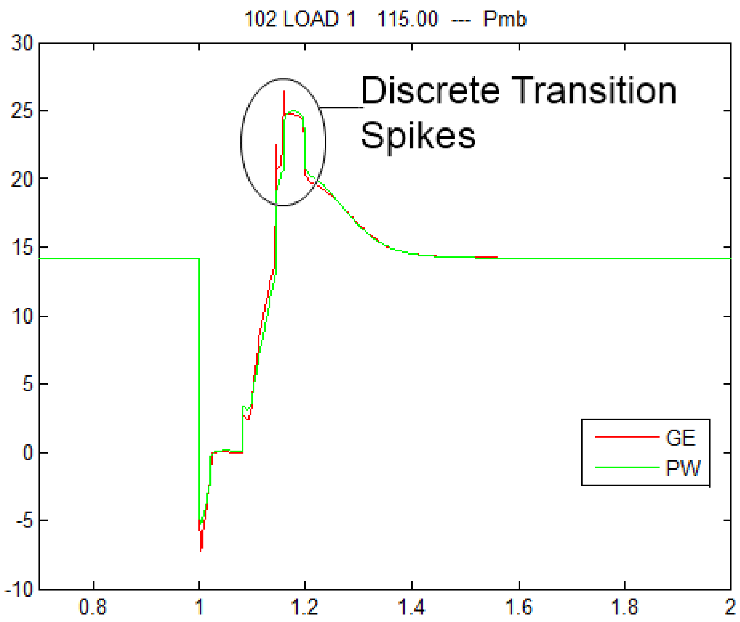
- Biggest remaining difference is the motor speed differences: What causes these?

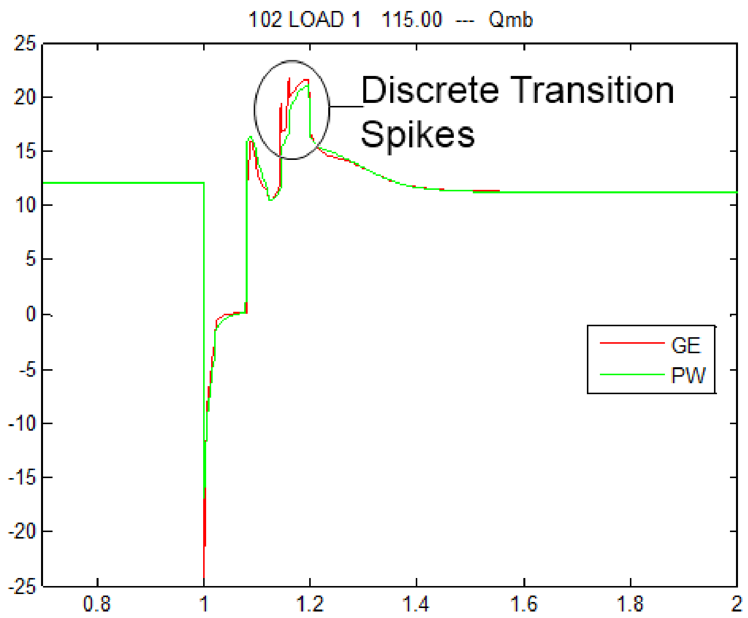


Open Question

Discrete Transition Spikes

- These spikes have little impact on the results, but one must be aware of them when comparing results.





Open Question

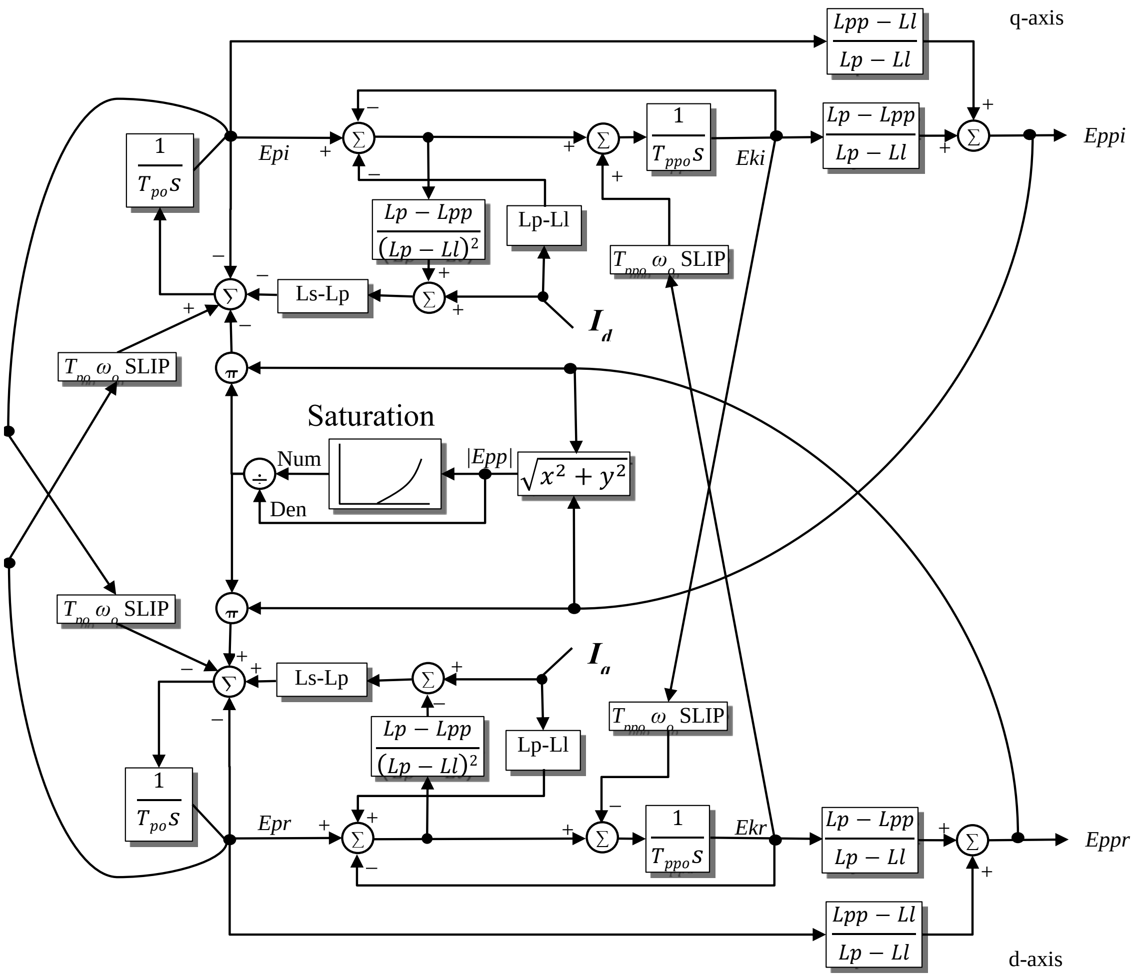
MOTORW difference with Induction Motor Models

- Induction motors can be represented by any of the following models
  - Load Models: CIM5, CIM6, CIMW
    - 7 Parameters: Ra, Xa, Xm, R1, X1, R2, X2
  - Generator Model: MOTOR1, GENIND
    - 7 parameters: Ls, Lp, Ra, Tpo, Lpp, Tppo, Ll
  - Load Model: MOTORW
    - 6 parameters: Ls, Lp, Ra, Tpo, Lpp, Tppo
- There is an algebraic relationship between the 7 parameters in CIMx and MOTOR1, so they are identical models
- MOTORW leaves out he “Ll” term

- For a single-cage motor [(Tppo = 0) or (Lpp=Lp)] all these models are identical
- Historically MOTORW models had input data that represented single-cage motors only
  - Old WECC MOTORW model always used Tppo = 0 and Lpp=Lp=0.17

Open Question

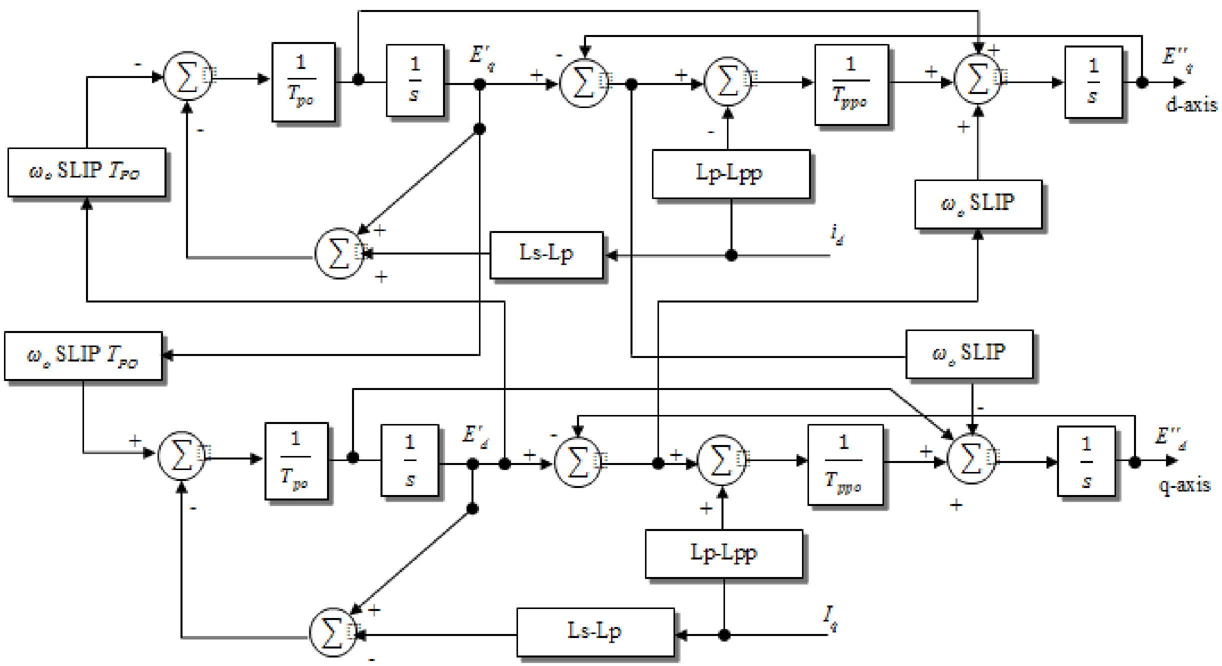
Standard Induction Motor Block Diagram



CIM5, CIM6, CIMW and MOTOR1

MOTORW is slightly different

- With a bit of thinking, you can prove to yourself that these are the same if Lpp=Lp and Tppo = 0



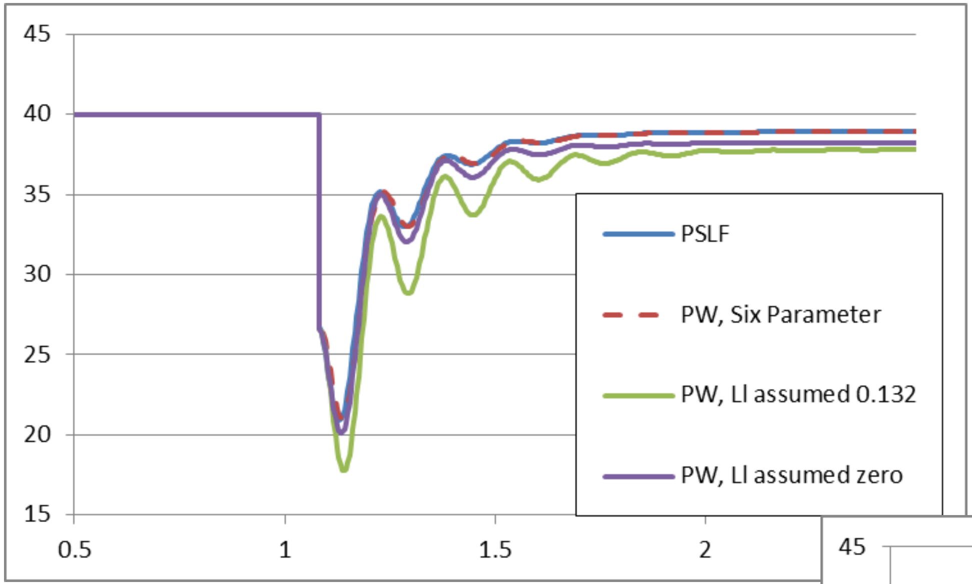
CIM5, CIM6, CIMW and MOTOR1

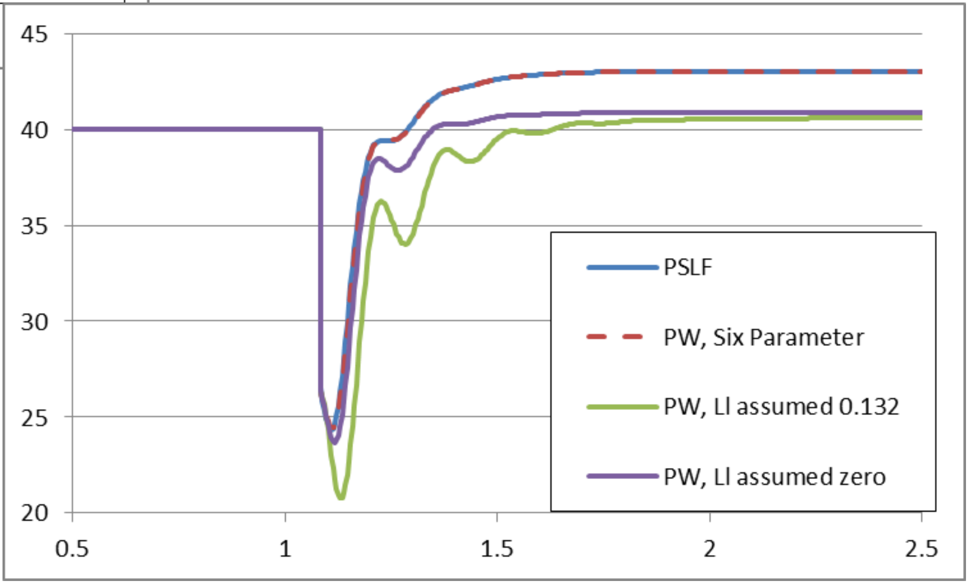
Open Question

Simulator Options

- Prior to July 17, 2014, PowerWorld Simulator assumed that the MOTORW model worked the same as CIM5 and assumed that
  - Ll = 0.8*Lpp
- Models are different however.
  - We can not just assume something link “Ll=0” or “Ll=Lpp”, etc…
- Starting July 17, 2014 PowerWorld has added an option on how to treat MOTORW
  - Default is to change to the alternative induction motor block diagram used for MOTORW

CIMx will never match MOTORW for a Double-Cage Motor





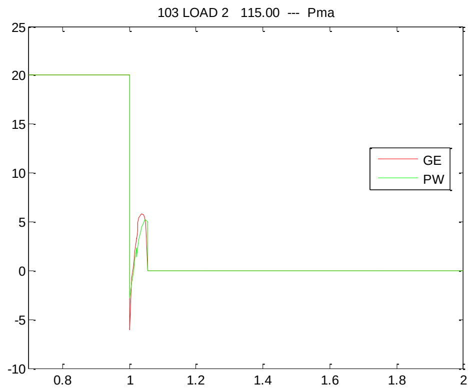
Final Results

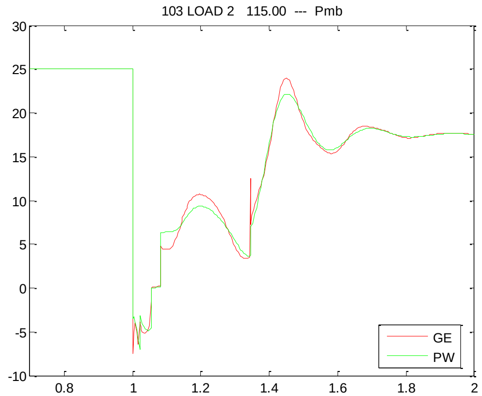
- The following slides show all the results for all the runs done

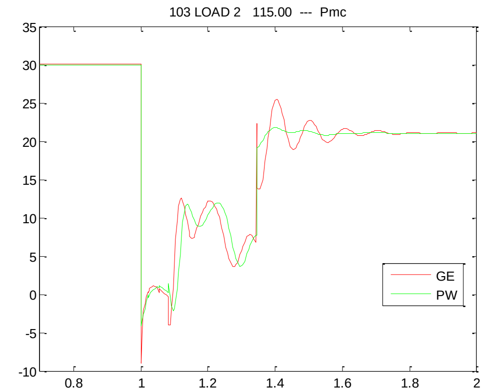
“Phase 1” Motor A, B, C
MW and Mvar Results

Motor A | **Motor B** | **Motor C**

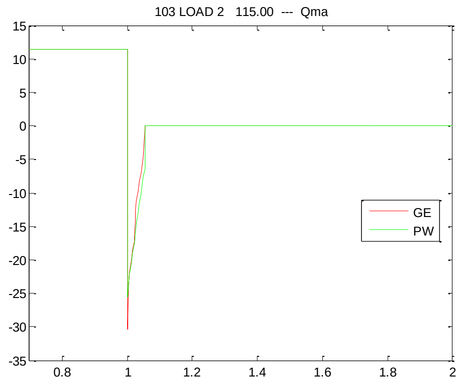
P [MW]

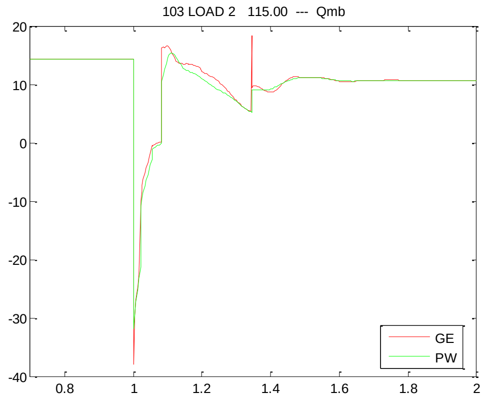


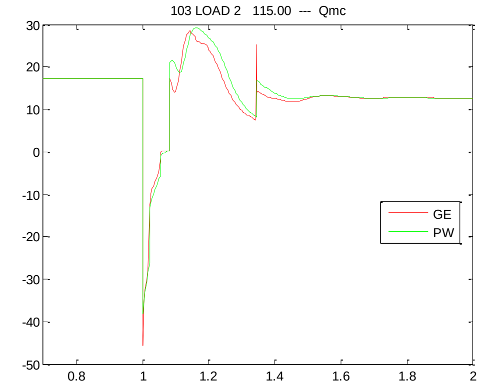




Q [Mvar]



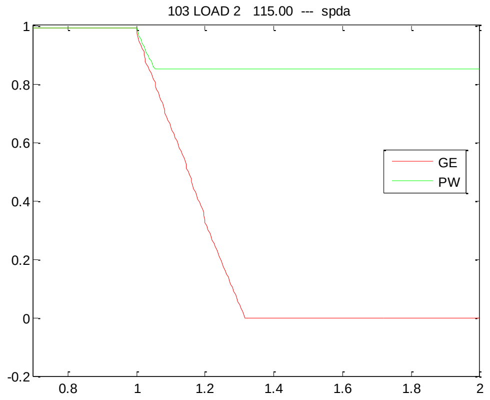


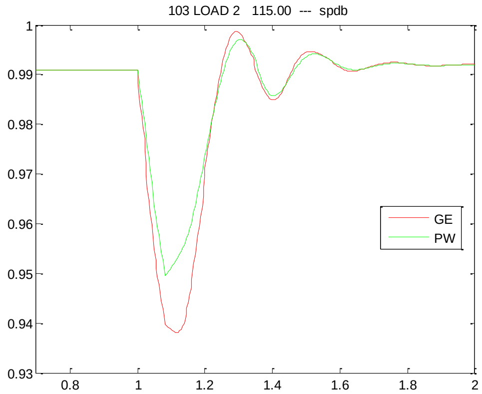


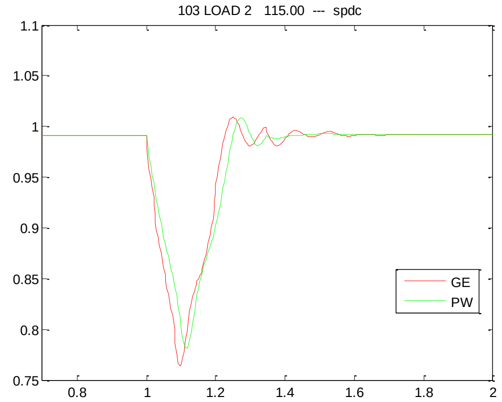
“Phase 1” Motor A, B, C Motor Speed Results

Motor A **Motor B** **Motor C**

Speed

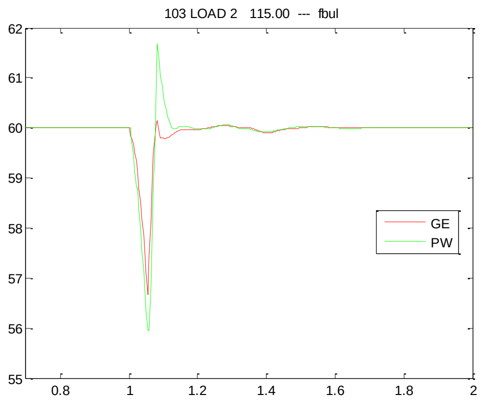




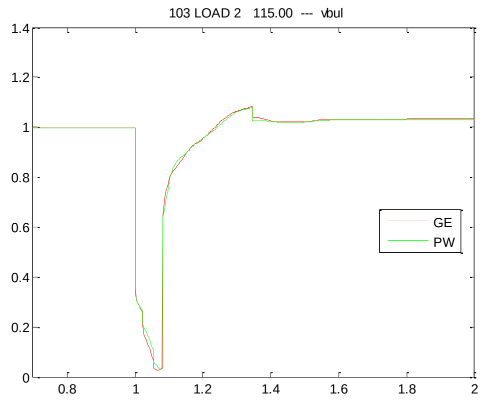


"Phase 1" Distribution Equivalent Voltage

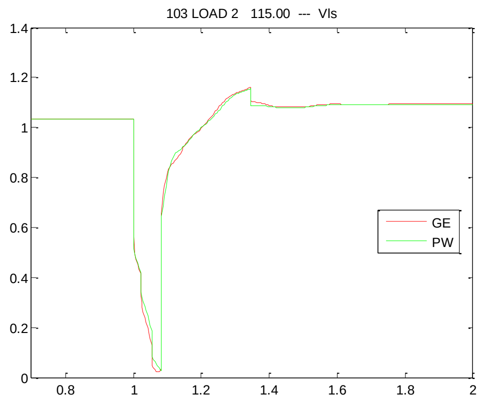
Frequency



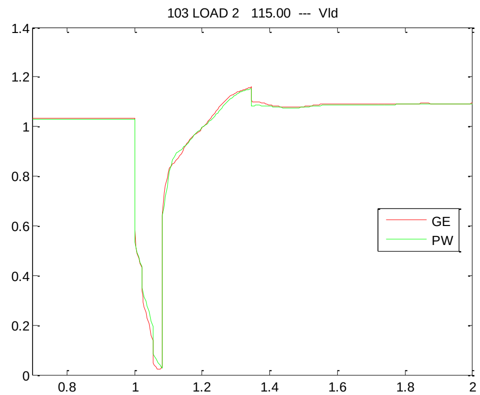
Voltage at Transmission



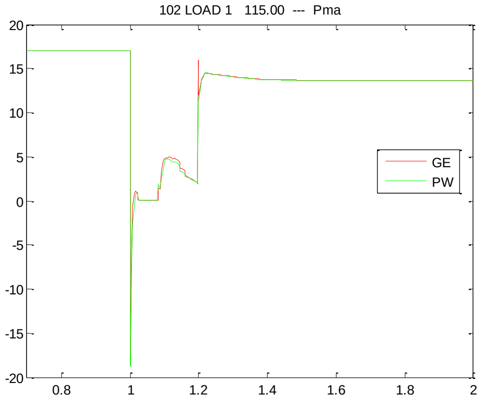
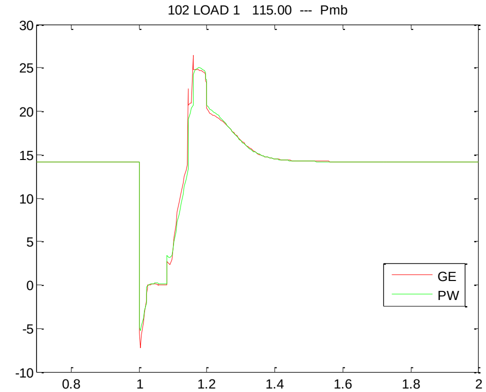
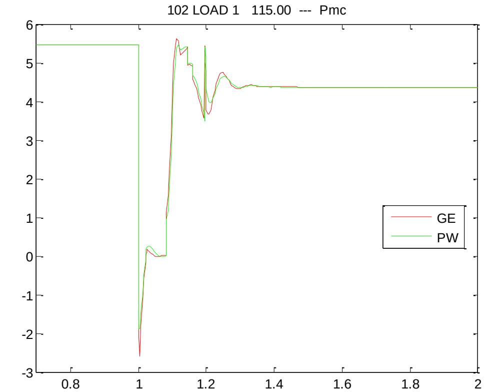
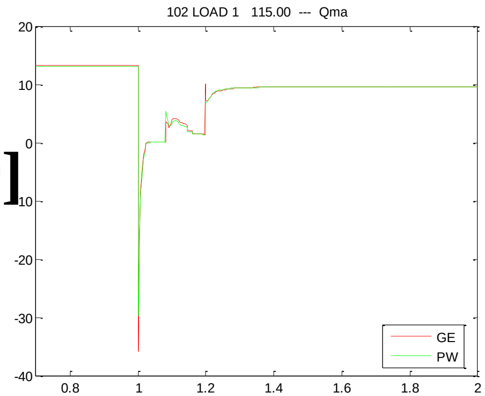
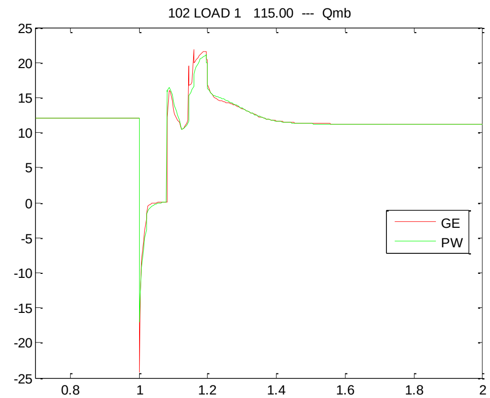
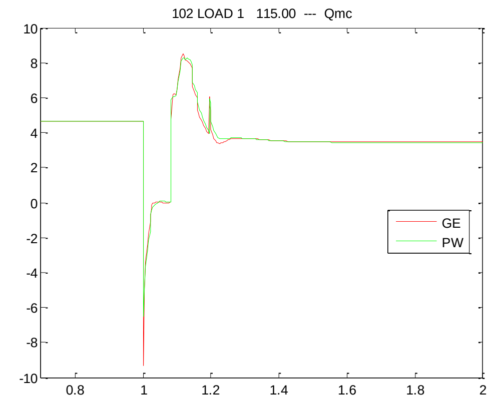
Voltage Low Side



Voltage at Load Bus

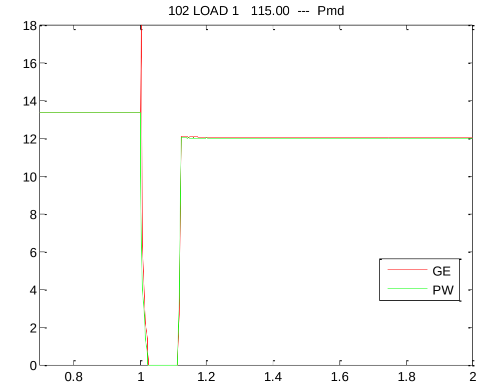


"Phase 2" Motor A, B, C MW and Mvar Results

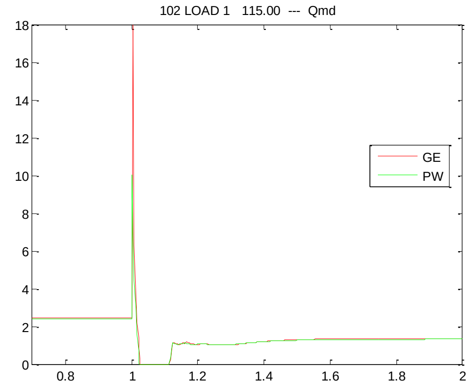
	Motor A	Motor B	Motor C
P [MW]			
Q [Mvar]			

"Phase 2" Motor D Power Result single-phase air-conditioner

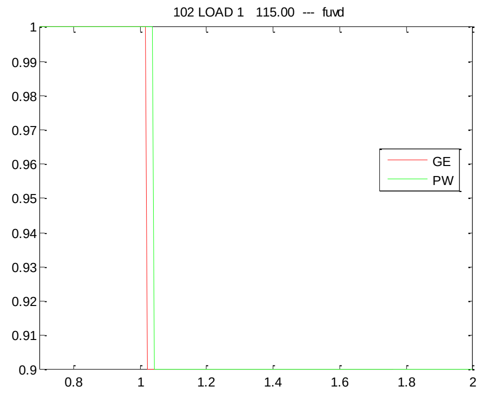
P [MW]



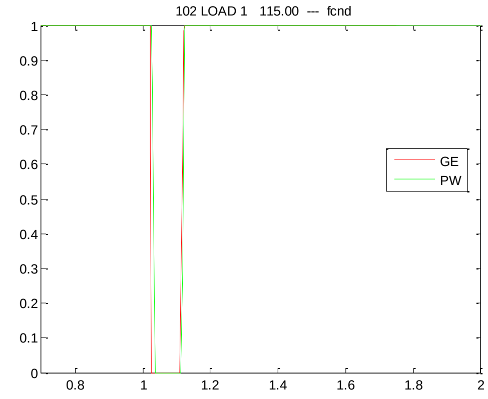
Q [Mvar]



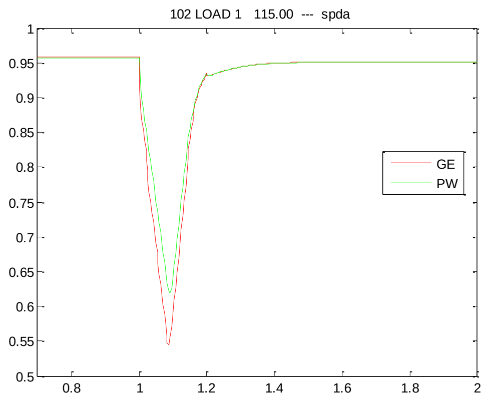
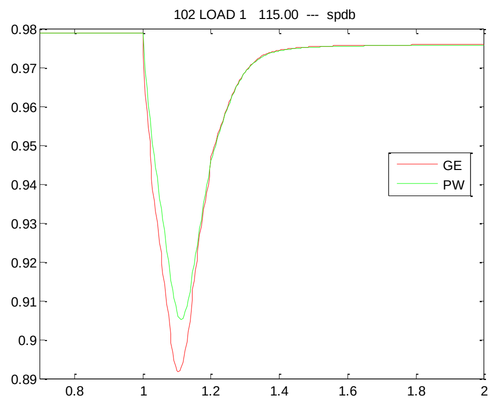
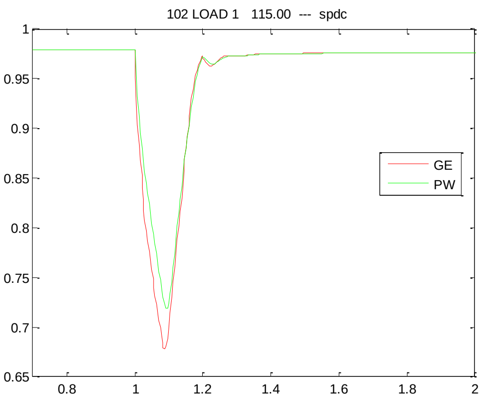
Under Voltage Multiplier



Contactor Multiplier

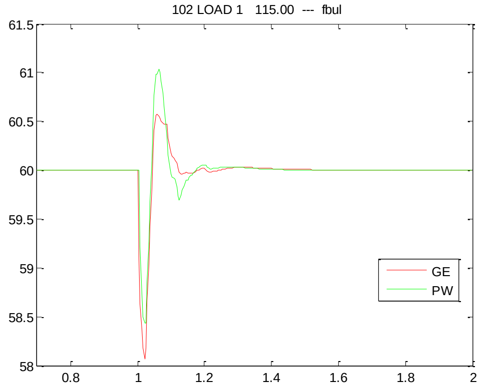


"Phase 2" Motor A, B, C
Motor Speed Results

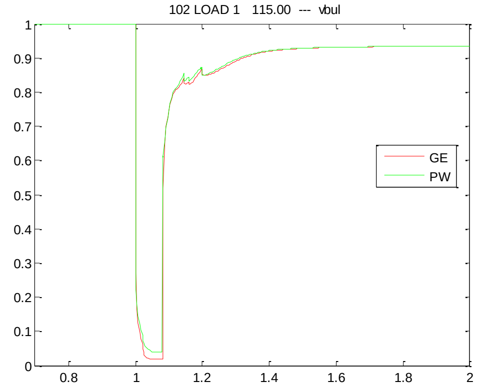
	Motor A	Motor B	Motor C
Speed			

"Phase 2" Distribution Equivalent Voltage

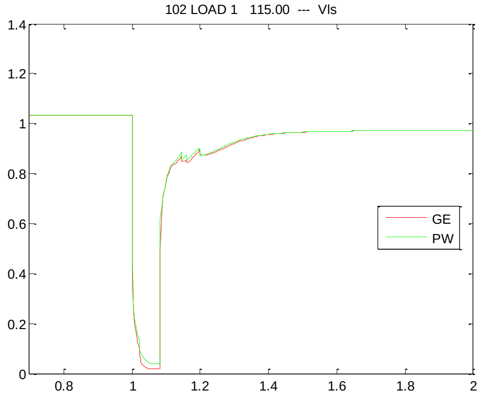
Frequency



Voltage at Transmission



Voltage Low Side



Voltage at Load Bus