U.S. DEPARTMENT OF ENERGY
Electricity Delivery & Energy Reliability
Advanced Grid Modeling
2014 Peer Review

High Fidelity "Faster than Real-Time" Simulator for Predicting Power System Dynamic Behavior

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Robert W. Galvin Center for Electricity Innovation
Illinois Institute of Technology
plus EII, ANL, Alstom Grid, McCoy Energy, ComEd, AltaLink
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Vision

- Aid operators in need – during cascading outages
- Predict actual complex, large-scale power system behavior "faster than real-time"
- Build the backbone of the hybrid real-time wide-area protection and control architecture

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Presentation Outline

- Participants
- Project Purpose
- Significance and impact
- Technical approach
- Technical accomplishments
- Conclusion

Participants (DOE plus…)

- Illinois Institute of Technology – Simulator development (TS3ph)
  - Alex Flueck (PI), Xu Zhang, Adrian Maldonado, Yagoob Alsharief, Yuan Zhi
- Argonne National Laboratory – Computational methods (PETSc)
  - Emil Constantinescu, Barry Smith, Shri Abhyankar
- Electrocon – Relay protection simulation (CAPE)
  - Jeff Quada, Paul McGuire, Don MacGregor, Daryl Coleman
- Alstom Grid – Verification and validation (TSAT, DTS)
  - Rene Avila-Rosales, Jay Giri, Manu Parashar
- McCoy Energy – Utility Advisory Group
  - Paul McCoy
- ComEd – Utility (Northern Illinois)
  - Tom Kay, Al Engelmann, Dave Schooley, Devon Summers, John Bettler
- AltaLink – Utility (Alberta, Canada)
  - Maureen Higgins, Tony Rutkunas, Mahdi Hajian

AGM Program and Project Purpose

- Accelerate performance and enhance accuracy of dynamic simulations to enable operators to maintain reliability and limit duration & size of blackouts
- Build a multidisciplinary community
  - Leverage modeling and simulation advances to more accurately represent dynamic behavior
  - Leverage math and computing advances to improve speed of dynamics simulations
- Develop a high fidelity “faster than real-time” dynamics simulator capable of predicting complex, large-scale power system behavior

- 5 -

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Significance and Impact

- Threats
  - Cascading outages
    - September 8, 2011 San Diego Blackout
    - August 14, 2003 Northeast Blackout
  - Severe weather
    - October 29, 2012 Superstorm Sandy
  - Malicious attack
  - Renewable resource integration
  - Voltage collapse & FIDVR
    - Induction motor load
  - Distribution system complexity
- Aid operators in their true time of need
- Steer clear of blackouts

- 6 -

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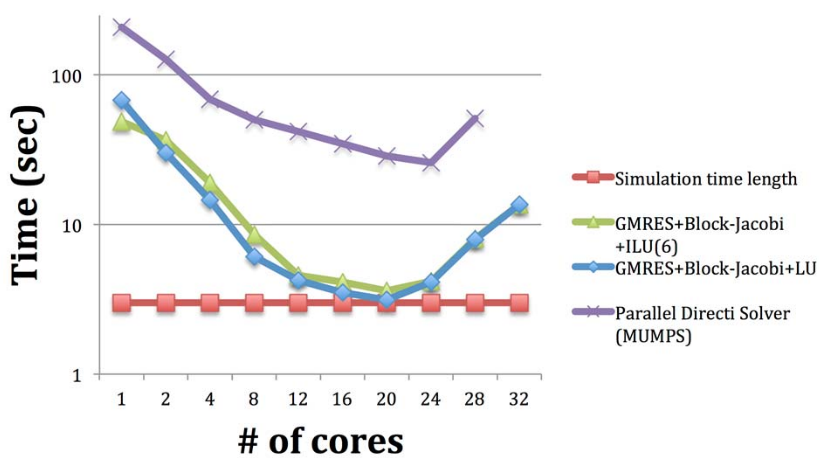
Technical Approach

- Improve speed of dynamics simulations
  - Leverage Portable, Extensible Toolkit for Scientific computation (PETSc) linear solvers, nonlinear solvers, time stepping algorithms, memory management, multi-core, many-core and possibly Graphical Processing Unit (GPU) processors
- Improve fidelity of dynamics simulations
  - Integrate new three-phase unbalanced network models, single-phase induction motor models, detailed generator models, detailed control models, and protection system models

Technical Accomplishments (previous work) - Almost faster than real-time for 2360 bus case



Technical Accomplishments - Utility Characteristics

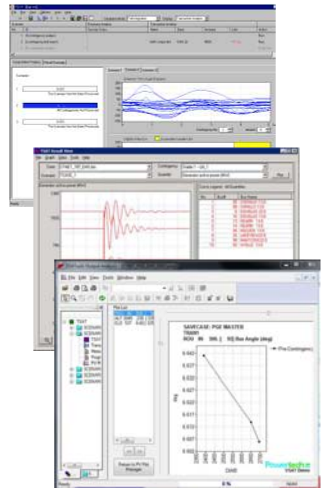
- ComEd
  - Tightly meshed
  - Large urban core
  - Concentration of very large generating units (nuclear)
- AltaLink
  - Long distances
  - Concentrated load and generation
  - Combination of active devices on system
- TVA
  - Broad EHV network
  - Many interconnections
  - Combination hydro-nuclear-fossil supply

Technical Accomplishments - Testing and Sharing

- Executed NDAs with utility partners
- Established testing procedure with Alstom Grid
- Tested socket communication with Electrocon
- Attended CAPE User Group Meeting (2013)
- Tested TS3ph with GENROU, ESDC1A, IEESGO
  - Three-phase fault, 0.1 sec duration, 10 sec simulation
  - Evaluated parallel GMRES iterative linear solver with ASM preconditioner
  - Evaluated parallel MUMPS direct LU linear solver
  - Evaluated parallel SuperLU direct LU linear solver

Technical Accomplishments (Alstom Grid) - TSAT Testing Environment

- Capabilities:
  - Angle limit determination
  - Transfer limit determination
  - Branch faults (single, two or three phases), tripping and reconnection, shunt switching
  - Faults of various types (three-phase, single phase, two phases to ground) at bus or anywhere on a branch
  - Generator tripping
  - Load shedding, ramping
  - Motor starting
  - Remedial actions
  - Prony analysis
  - Stressed conditions



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Technical Accomplishments - PETSc and Utility Data

- Integrated PETSc Time Stepping routines into TS3ph
  - Allows us to leverage future PETSc enhancements
- Established benchmark system based on utility partner data (approximate numbers of devices)
  - 18.5k buses
  - 2k generators
  - 12k loads
  - 21k transmission branches (lines, transformers)

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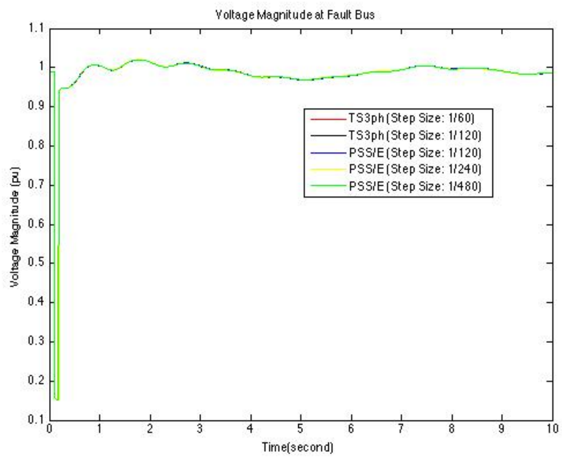
Technical Accomplishments (utility simulation) - GENROU, ESDC1A, IEESGO Verified



- 13 -

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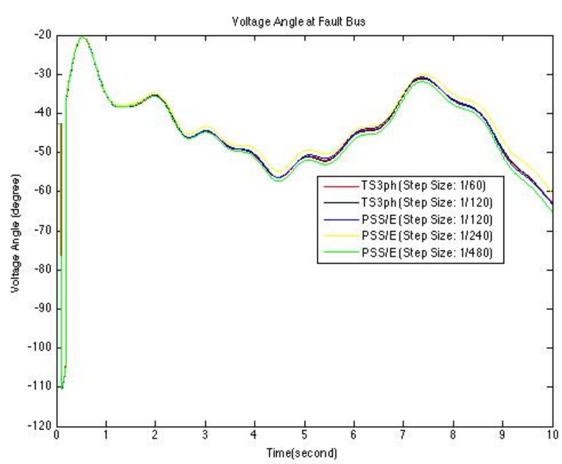
Technical Accomplishments (utility simulation) - GENROU, ESDC1A, IEESGO Verified



- 14 -

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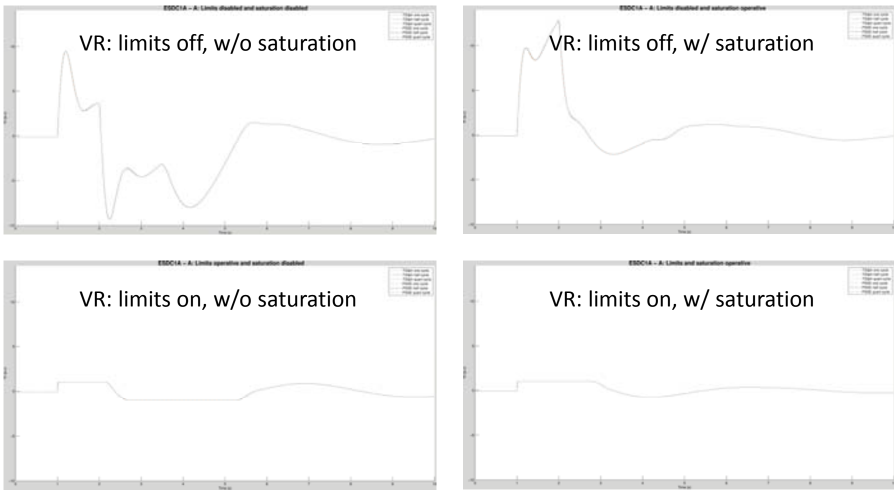
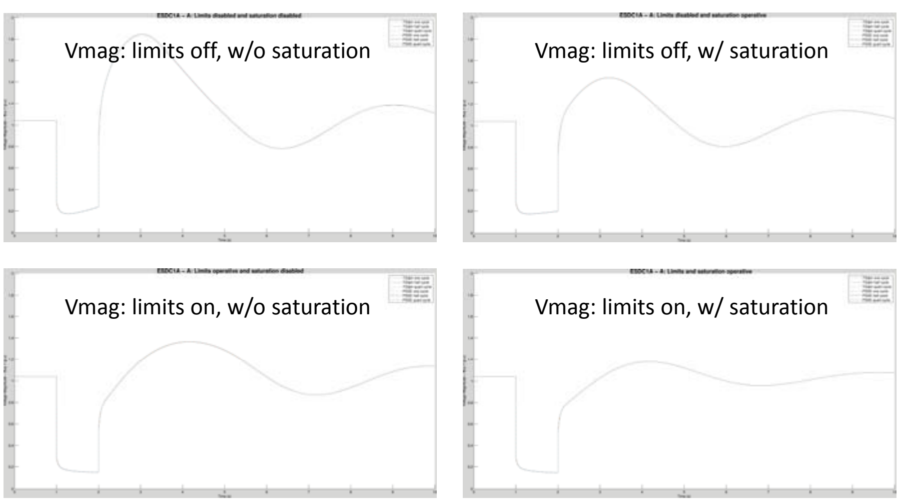
Technical Accomplishments (Voltage Regulator) - ESDC1A Regulator Limits & Saturation Verified



- 15 -

Technical Accomplishments (Terminal Voltage) - ESDC1A Regulator Limits & Saturation Verified

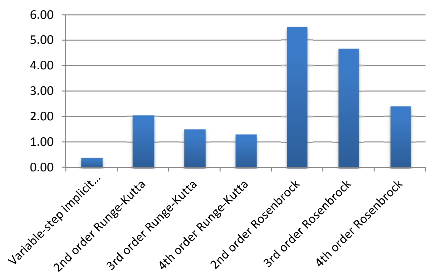


- 16 -

Technical Accomplishments (ANL) - Variable Time Stepping

With averaged local-truncation error

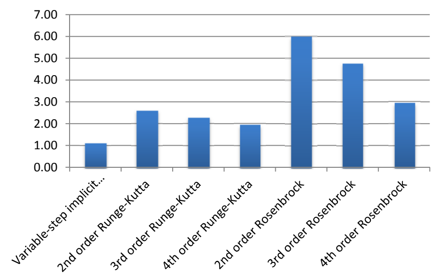
$$||e||_2 = \sqrt{\frac{1}{n}\sum_{k=1}^{n} |y_k - \tilde{y}_k|^2}$$



Relative speed-up compared with fixed-step implicit trapezoidal method

With max local-truncation error

$$||e||_\infty = \max_{k=1\ldots n} |y_k - \tilde{y}_k|$$



Relative speed-up compared with fixed-step implicit trapezoidal method

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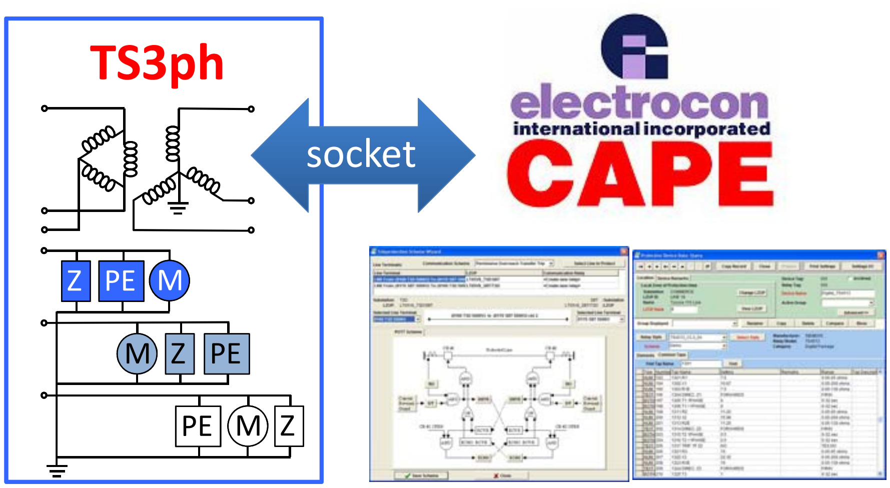
Technical Accomplishments - Component Models



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Technical Accomplishments (ANL & EII) - Solution Methodology

- Time stepping (fixed, adaptive) plus new non/linear solvers with PETSc
- Socket communication with CAPE (Windows)
  - TS3ph passes clock and voltage & current signals to CAPE
  - TS3ph receives breaker operations & times
- CAPE API released Sep 30, 2013
  - Simulation 2-3 times faster due to efficiency improvements
- CAPE multi-threading via Open MP
  - 3.5 times faster on four-core machine; 16 cores next
- By end of Year 2: parallel solution on Linux cluster with InfiniBand interconnect and possibly accelerators

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Technical Goals (near-term)

- Verification testing with Alstom Grid
  - ESCA 60 network, dynamics, stressed systems
- Verification testing with Electrocon
  - TS Link network, dynamics, SPS/RAS
- Validation studies with utility data under stressed and unbalanced conditions
  - ComEd network & protection data
    - Load, generator, SVC, wind turbine response
  - AltaLink network data & protection data
    - SVC, HVDC, wind turbine, large load response
  - Other utility partner data?

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Technical Goals (long-term)

- Simulate voltage instability, FIDVR
  - Modeling focus: Loads, generators, network controls
- Simulate cascading outages
  - Modeling focus: Relay protection, RAS, SPS

Conclusion

- Looking forward to achieving our goals in AGM:
  - High fidelity simulation results with actual utility data
  - "Faster than real-time" dynamics simulation
  - Accurate predictions of power system dynamics behavior
    - Load dynamics
    - Control dynamics
    - Protection dynamics
- Looking forward to building the community
- Looking forward to the next challenge…

Acknowledgements/Contacts

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- 23 -

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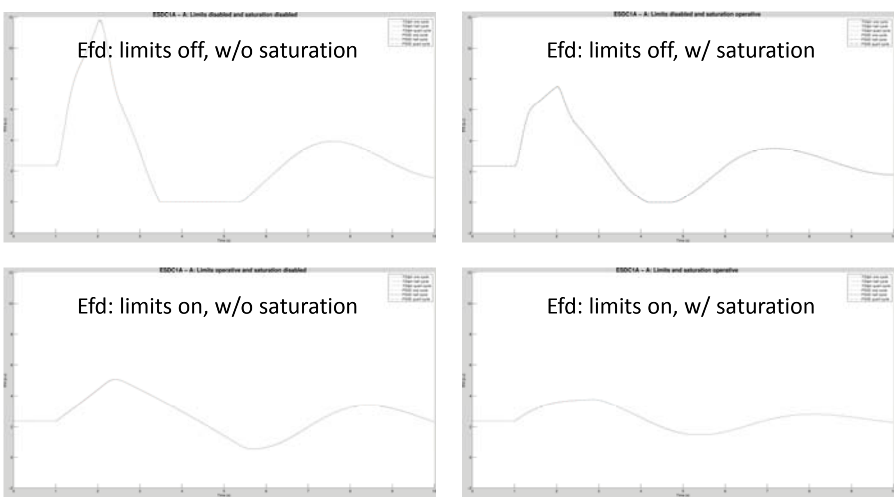
Technical Accomplishments (Field Voltage) - ESDC1A Regulator Limits & Saturation Verified



- 24 -

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Project Summary Slide

- If you are willing… as the first slide in the backup section, please include one slide that summarizes your project which DOE could use in other presentations (with acknowledgement) or link to on the DOE website in an effort to enhance visibility of the project(s) as part of a broader program portfolio.
- This slide does NOT need to hold to the peer review template. Creativity is encouraged.

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