Pacific Northwest NATIONAL LABORATORY

WECC Modeling and Validation Subcommittee meeting
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GridPACK-Wind: High-Performance Modeling and Simulation Tool for Wind Integration

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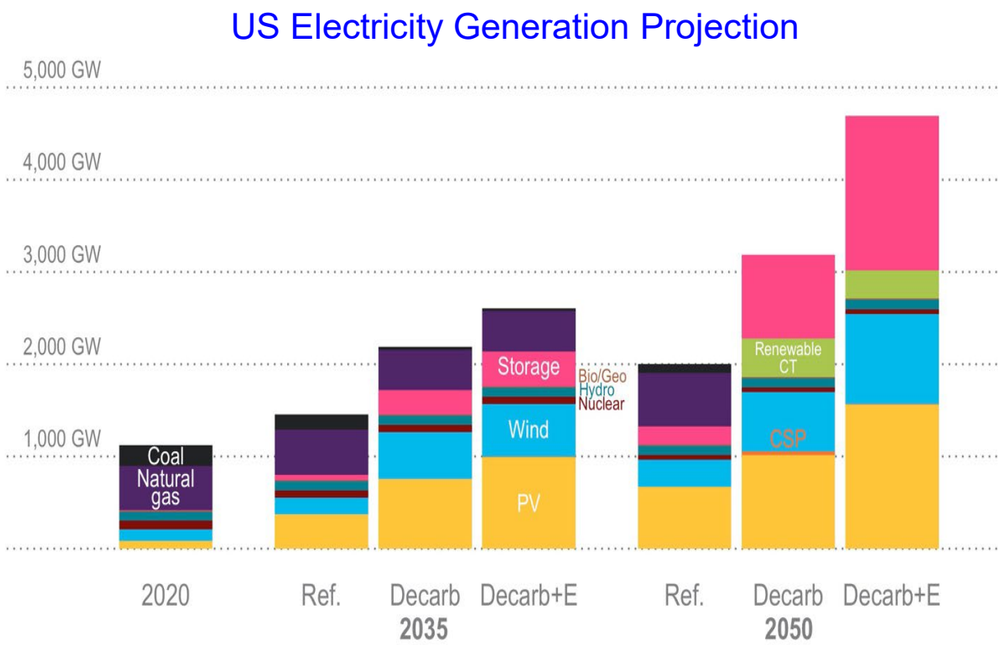
System challenges in clean energy and decarbonization



Credit: DOE EERE SETO Solar Futures Study 2021.

- System trends
  - 3.5X projected capacity increase from 2020
  - Expected retirement of conventional generation sources
- System challenges
  - Increased uncertainty
  - Low-inertia systems with IBRs
  - Power electronics heavy
- Modeling and simulation challenges
  - Large number of scenarios
  - Larger/more complex EMT system model
  - Slow simulation speed

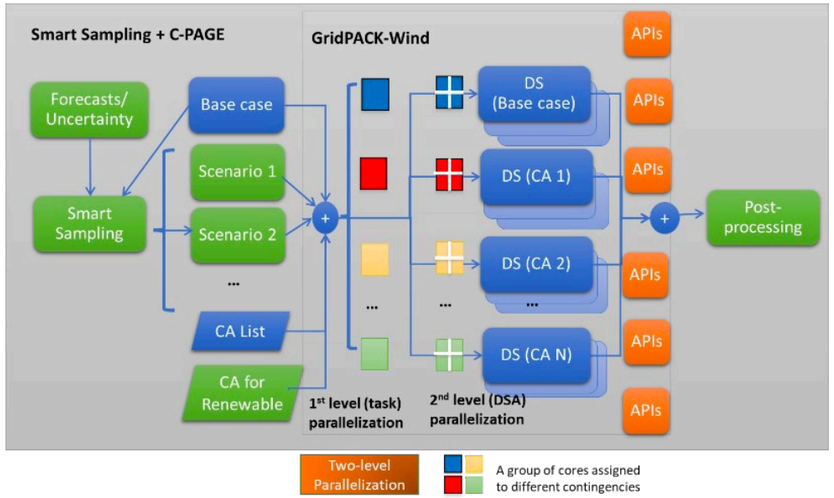
GridPACK-Wind: project overview

- Funded jointly by DOE EERE-WETO and DOE-OE AGM
- Duration: Three years. Started June 2022
- High-performance (parallel computing) dynamics simulation for wind-heavy systems
- GridPACK-Wind: an extension of GridPACK for wind heavy systems
  - On-shore and off-shore wind plant and controller models
  - Uncertainty quantification through dynamic stability analysis
  - Large-scale high-performance EMT simulation

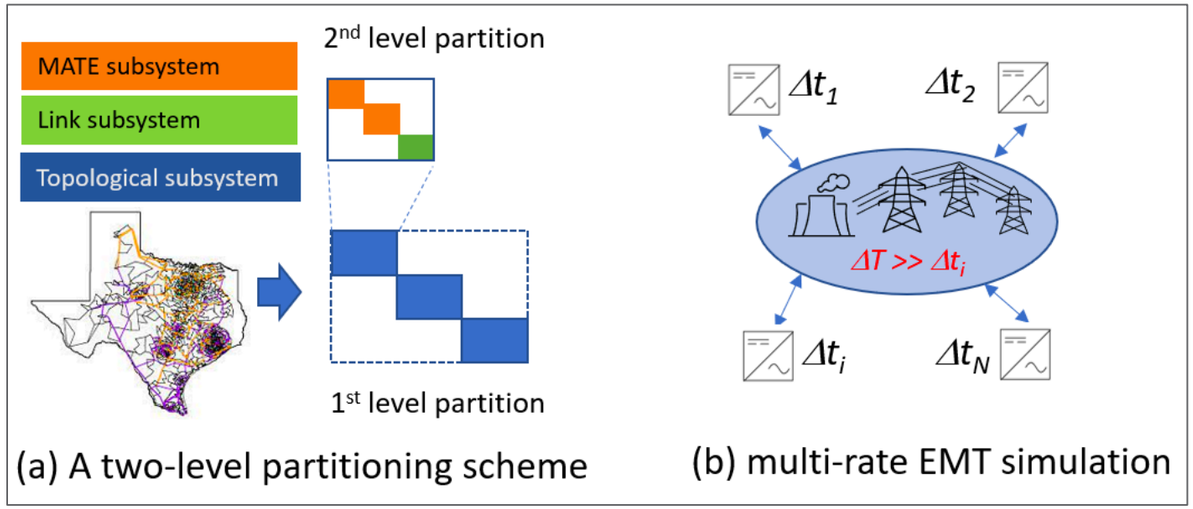
GridPACK-Wind: technical thrusts

- Three technical thrusts:
  1. Massive dynamic contingency analysis for wind-uncertainty scenarios
  2. Electromagnetic simulation engine
  3. Validation and performance assessment

Dynamic contingency analysis

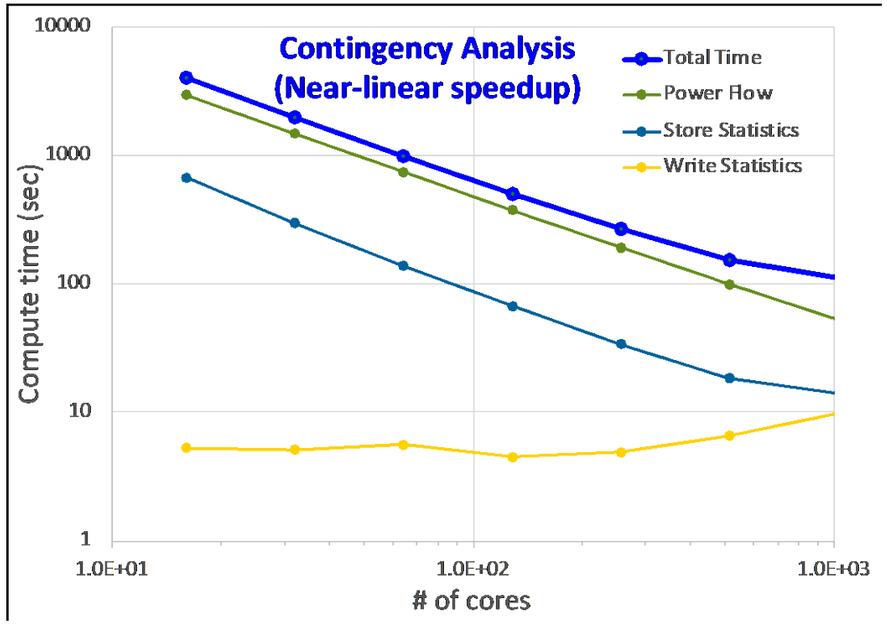


EMT simulation engine



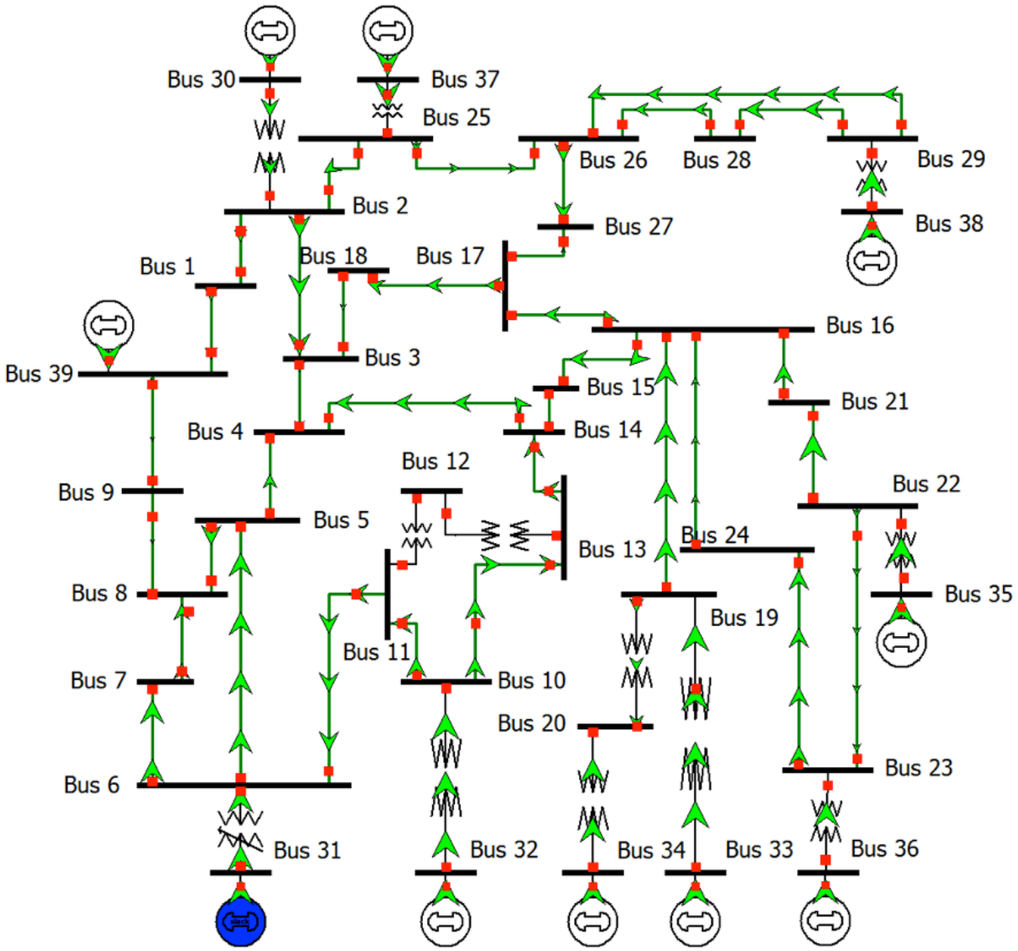
GridPACK™, www.gridpack.org

- GridPACK – an open-source grid-specific HPC programming library/framework
- GridPACK functionality
  - Power Flow and Contingency Analysis (CA)
  - Transient Simulation and Dynamic Security Assessment (DSA), under uncertainty with 2-level parallelism
  - Task manager to support Windows-based tools
  - Real-time path rating
  - Cloud version
- GridPACK application examples
  - HPC-powered remedial action schemes
  - WECC path rating studies in 10 minutes
  - ML-based emergency control
  - T & D co-simulation (GridPACK + HELICS + GridLAB-D) for large-scale inverter-based system studies

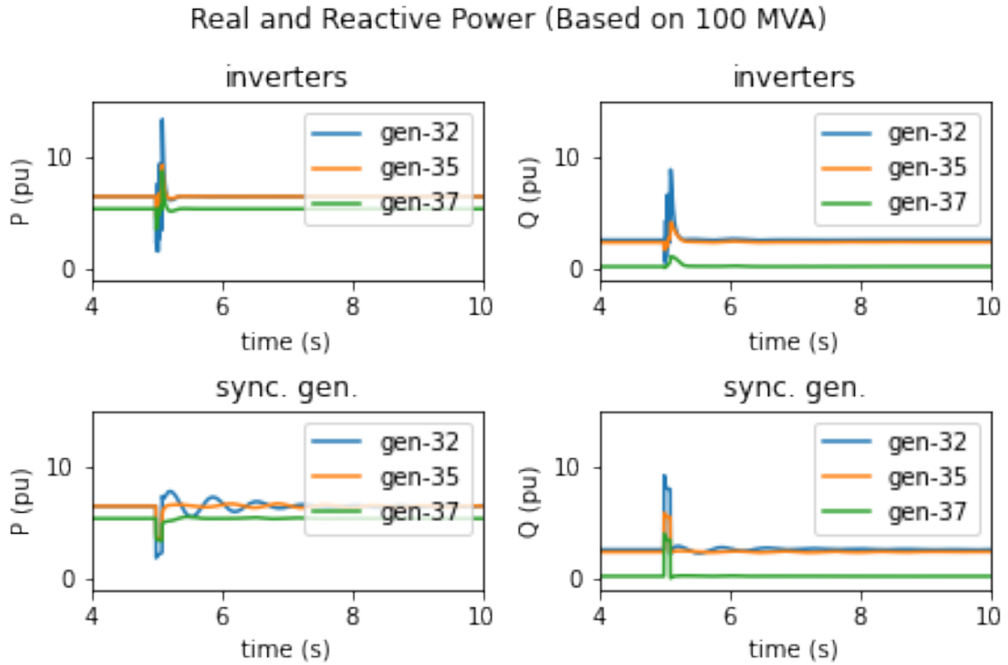


No. of Cores	20 sec Full WECC Transient simulation (sec)
1	72.9
2	45.0
4	31.0
8	23.0
16	19.5

Existing IBR model components in GridPACK

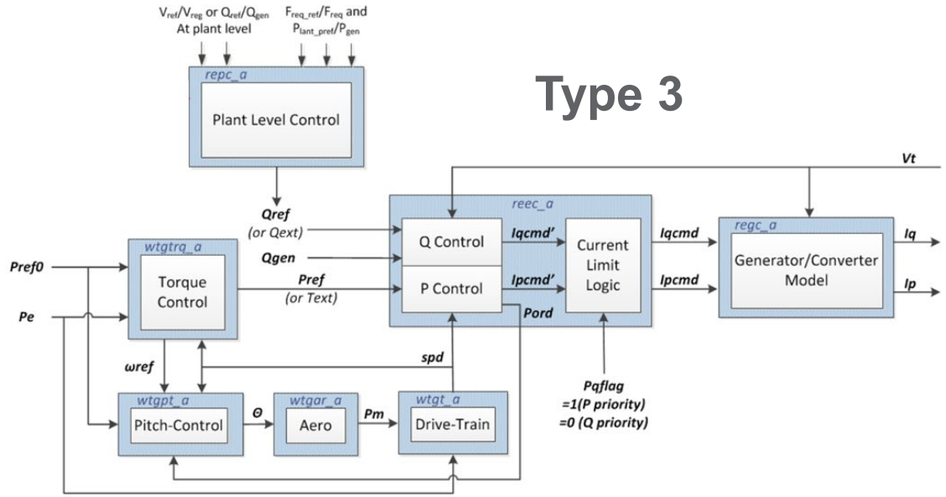


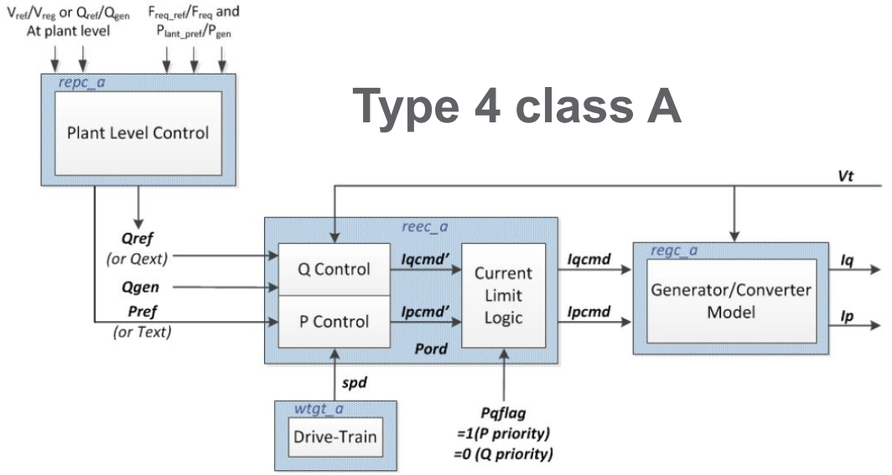
- Existing IBR component models in GridPACK:
  - Grid-following: REGC_A, REEC_A, REPC_A (Type 4 wind without drive train model)
  - Grid-forming: droop-controlled inverter model GFMDRP_A[1] (Assume constant DC-side voltage)
- In this study, the original synchronous generators are replaced by grid-following inverters at Buses 32, 35 and 37
- A 0.1s fault is applied at Bus 4

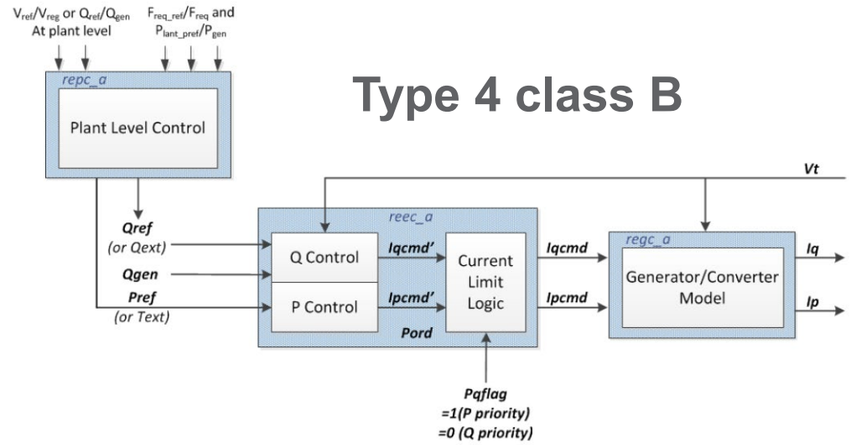


1. https://www.wecc.org/Reliability/Model%20Specification%20of%20Droop-Controlled,%20Grid-Forming%20Inverters_PNNL-V2-Final.pdf

Candidate wind generator models for including in GridPACK





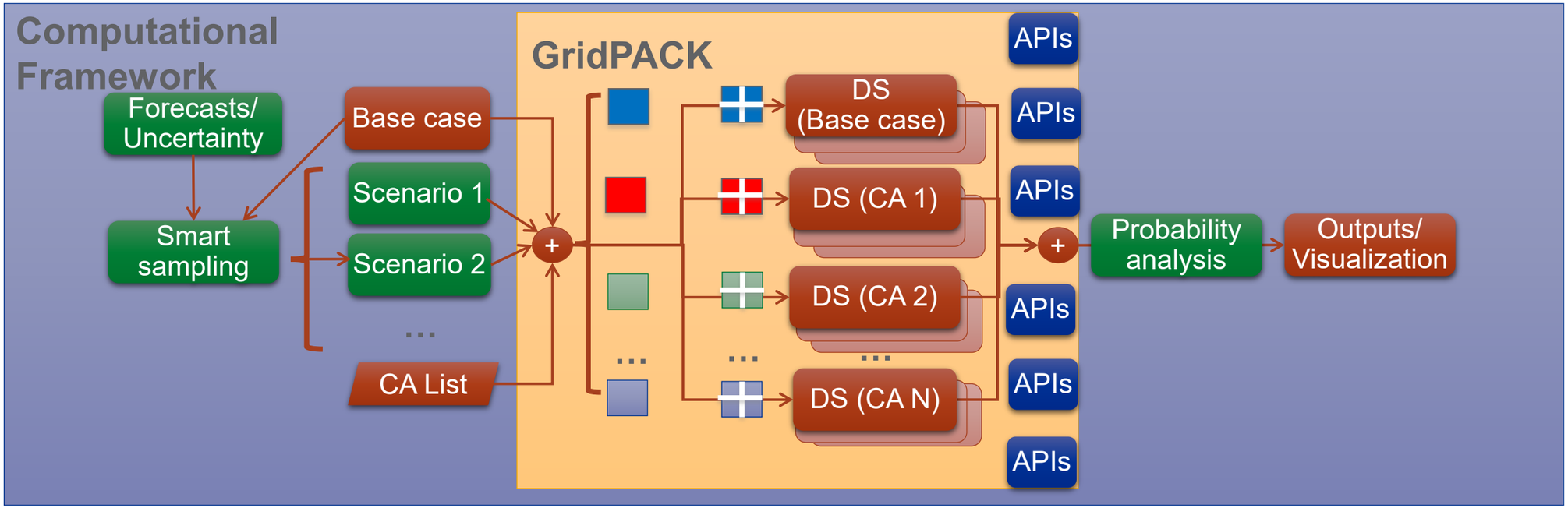


RES	Model combination
Type-3 WTG	REGC_A(OR_B), REEC_A(OR_D), REPC_A, WTGT_A, WTGA_A, WTGP_A, WTGQ_A
Type-4 WTG	REGC_A(OR_B), REEC_A(OR_D), REPC_A (Optional: WTGT_A; Preferred WTGT_B when available)

1. WECC REMTF – Type 3 Generic Wind Turbine Generator Model (Phase II)
2. WECC REMTF – Type 4 Generic Wind Turbine Generator Model (Phase II)

Dynamic security assessment (DSA) under uncertainty

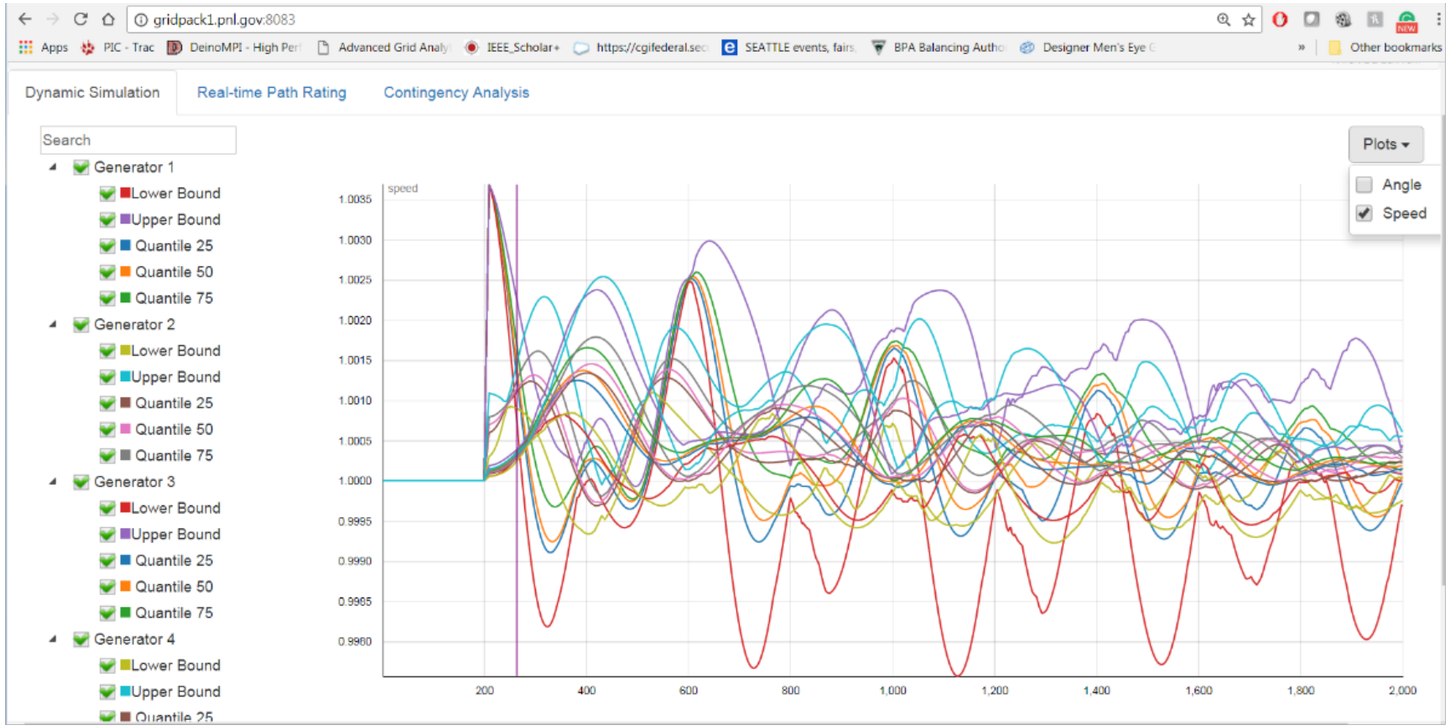
- GridPACK application for uncertainty analysis (includes contingencies)



Prior results of DSA on ESCA-60 bus system

Simulation time (sec)	10
Time step (sec)	0.005
# of scenarios	127
# of contingencies	10
# of cases	1270
# of monitored generators	4

# of cores	Time (sec)	Speedup
2	240	2
5	100	4.8
11	50	9.6
23	23	20.5
46	12.5	38.3



Variable time-stepping in GridPACK

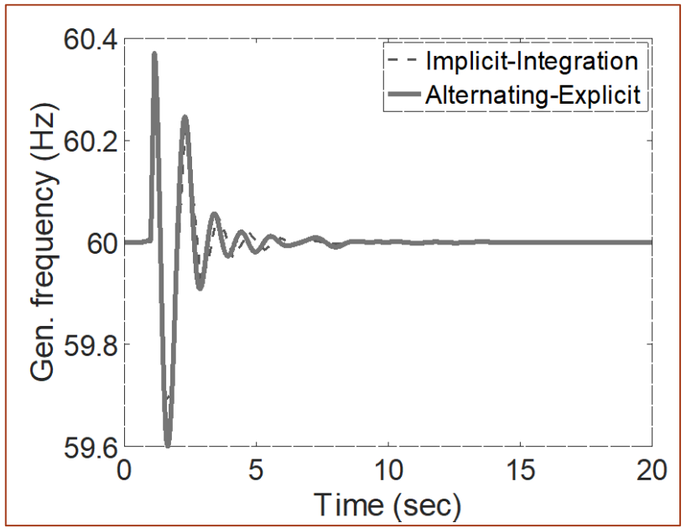
- Implicit integration algorithms
  - Backward Euler, Trapezoidal, Runge-Kutta, Rosenbrock, BDF
- Variable time-stepping

$$h_{n+1} = h_n \left(\frac{\epsilon_{abs} + \max(x_n, \hat{x}_n)\epsilon_{rel}}{||x_n - \hat{x}_n||} \right)^q$$

- Handling discontinuities

$$\begin{cases} x - x^+ = 0, & \text{if } x \geq x^+ \\ x - x^- = 0, & \text{if } x \leq x^- \\ \dot{x} = f(x, y), & \text{otherwise} \end{cases}$$

- Accuracy



- Performance

# of cores	Alternating-Explicit	Implicit-Integration
1	72.32	47.63
2	42.1	32.51
4	25.8	18.73
8	18.1	14.59
16	18.1	12.91
32	21.5	15.21

S. Abhyankar, R. Huang, S. Jin, B. Palmer, W. Perkins, Y. Chen, "Implicit-Integration dynamics simulation with the GridPACK framework", Proceedings of 2021 IEEE Power & Energy Society General Meeting

GridPACK-Wind: project team

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- Shri Abhyankar (PI)
- Yousu Chen
- Yuan Liu
- Bruce Palmer
- Bill Perkins
- Xueqing Sun

CLEMSON UNIVERSITY

- Shuangshuang Jin

RTE Réseau de transport d'électricité

- Benjamin Donnot
- Jereme Picault

Industry advisors

ISO new england

pjm

MISO

EVERSOURCE

BONNEVILLE POWER ADMINISTRATION

PGE

California ISO

GridPACK-Wind: project timeline

- Three Years: 06/01/2022 – 05/31/2025
- FY22
  - Extend **dynamic contingency analysis** for wind uncertainty
  - Wind power plant models
  - Variable time-stepping dynamics simulation
- FY23
  - Dynamic contingency analysis for synthetic Texas system with wind uncertainty scenarios
  - **EMT simulation engine core** development including typically electromagnetic models
- FY24
  - EMT simulation engine development incorporating on-shore and off-shore wind plant models
  - Interface GridPACK-Wind with RTE France's Grid2Op tool
- FY25
  - GridPACK-Wind performance assessment and validation, incl. Grid2Op + GridPACK-Wind

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Summary

- GridPACK-Wind
  - Three-year project funded by DOE-EERE and DOE-OE AGM
  - High-performance modeling and simulation for wind heavy systems
- Looking for inputs on
  - Modeling suggestions for on-shore and offshore wind plants
  - Example power grid networks for testing dynamics simulation, EMT simulation
  - Data/models for testing/validation
  - Any comments, suggestions

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Thank you

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