Pacific Northwest NATIONAL LABORATORY

GridPACK™: An HPC Platform for Better Grid Efficiency and Resilience

FERC Technical Conference: Increasing Real-Time and Day-Ahead Market Efficiency and Enhancing Resilience through Improved Software

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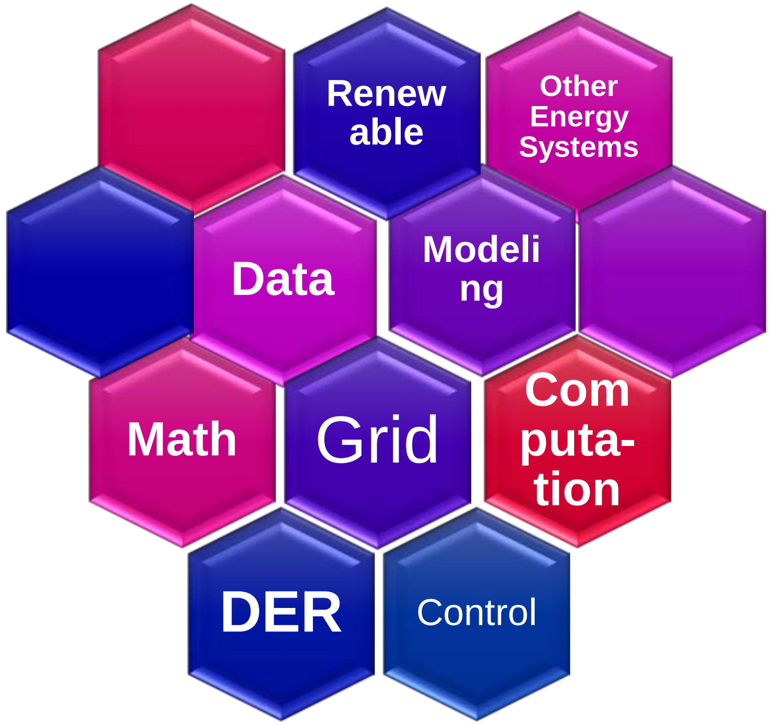
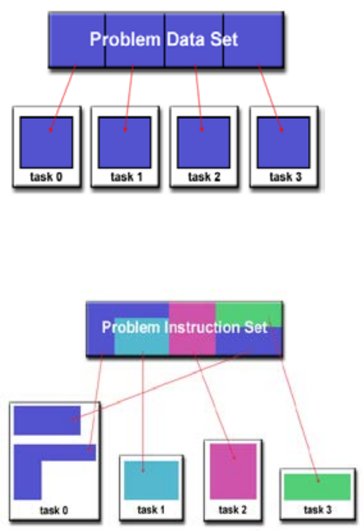
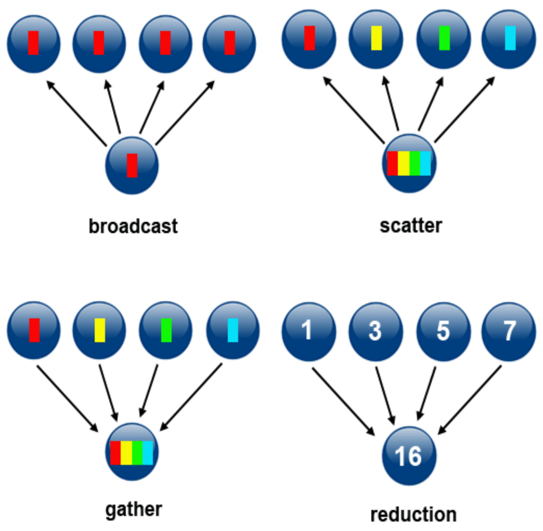
Background

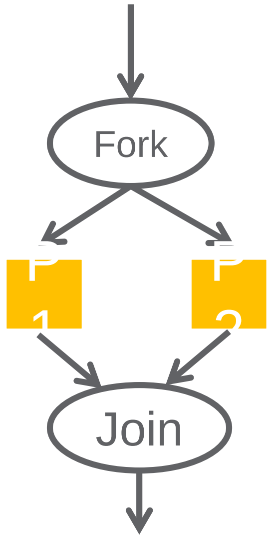
- The power grid is growing more complex, more dynamic with more renewables and smart grid technology
  - Increased grid complexity in modeling and simulation
  - Increased challenge in operation and control
    - ✓ Requiring faster operator responses
- Today's tools are not sufficient to handle the increased complexity
  - Dominated by serial codes
  - Take longer time for more complex applications
    - ✓ More challenging for dynamic power grid

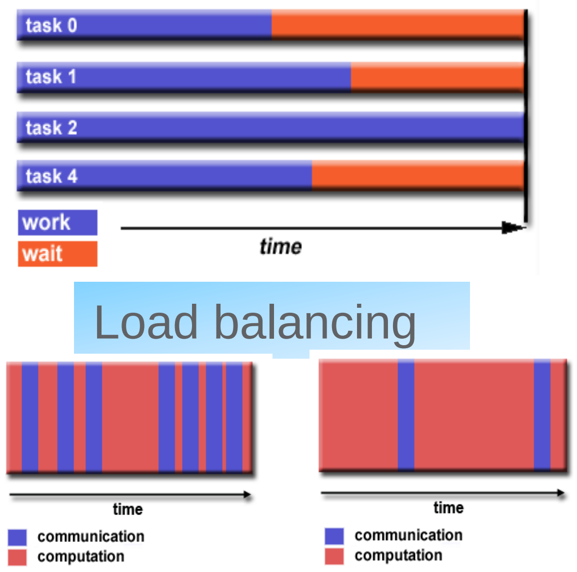


Challenge: HPC Implementation Is NOT Easy









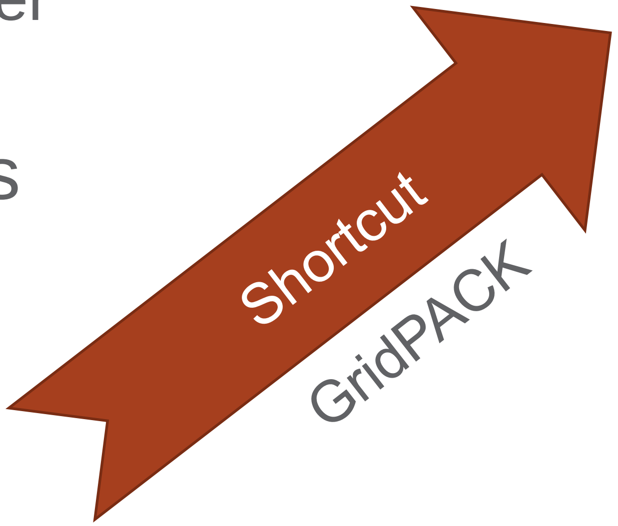
decomposition | Communication | Synchronization | Granularity

Be aware of Data Dependency!

- Difficult to extend vendors' legacy source code to HPC version
  - Need to re-organize/rewrite the code
- Most of power system engineers have little experience in HPC programming

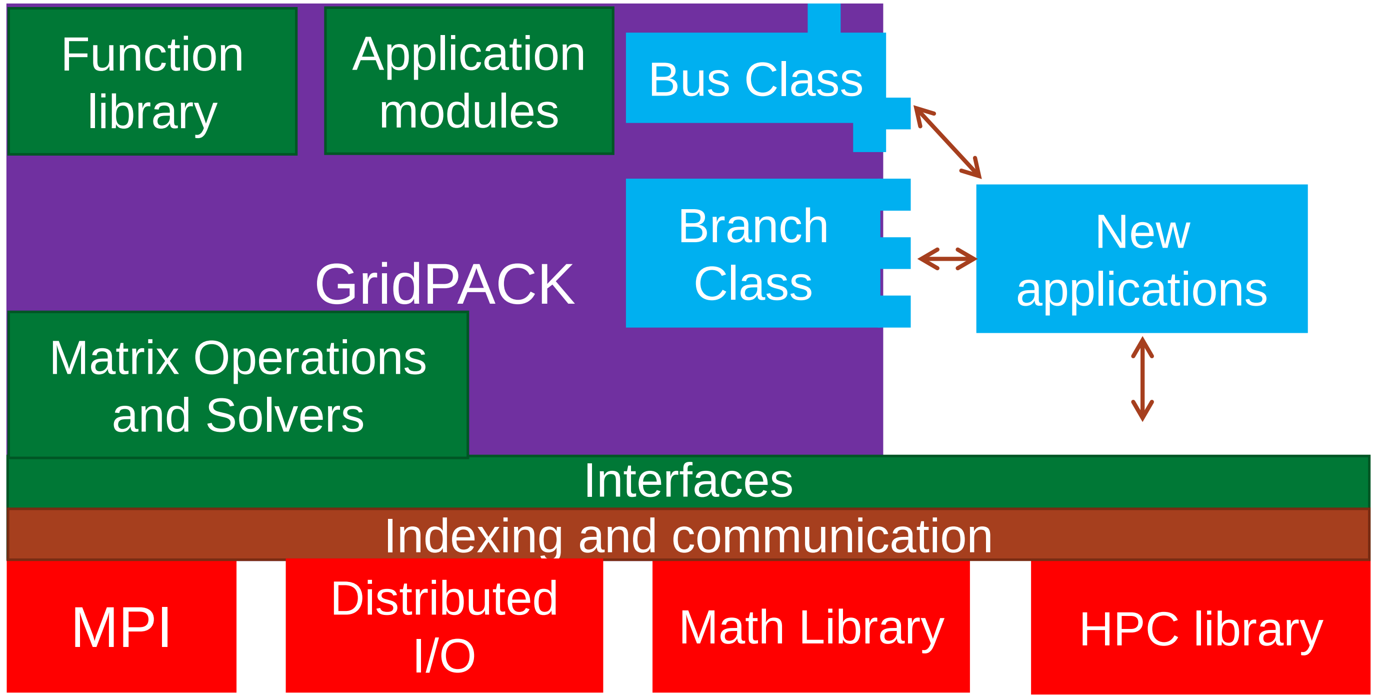
GridPACK^{TM} Objective

- An open source grid-specific HPC programming library/framework
  - Lower the threshold of HPC development
  - Allow power grid application developers to focus on algorithms, instead of parallel computing
  - Reduce the cost and effort of developing HPC power grid simulations
- A shortcut to develop and test HPC applications
- An vehicle to test with vendors’ legacy codes



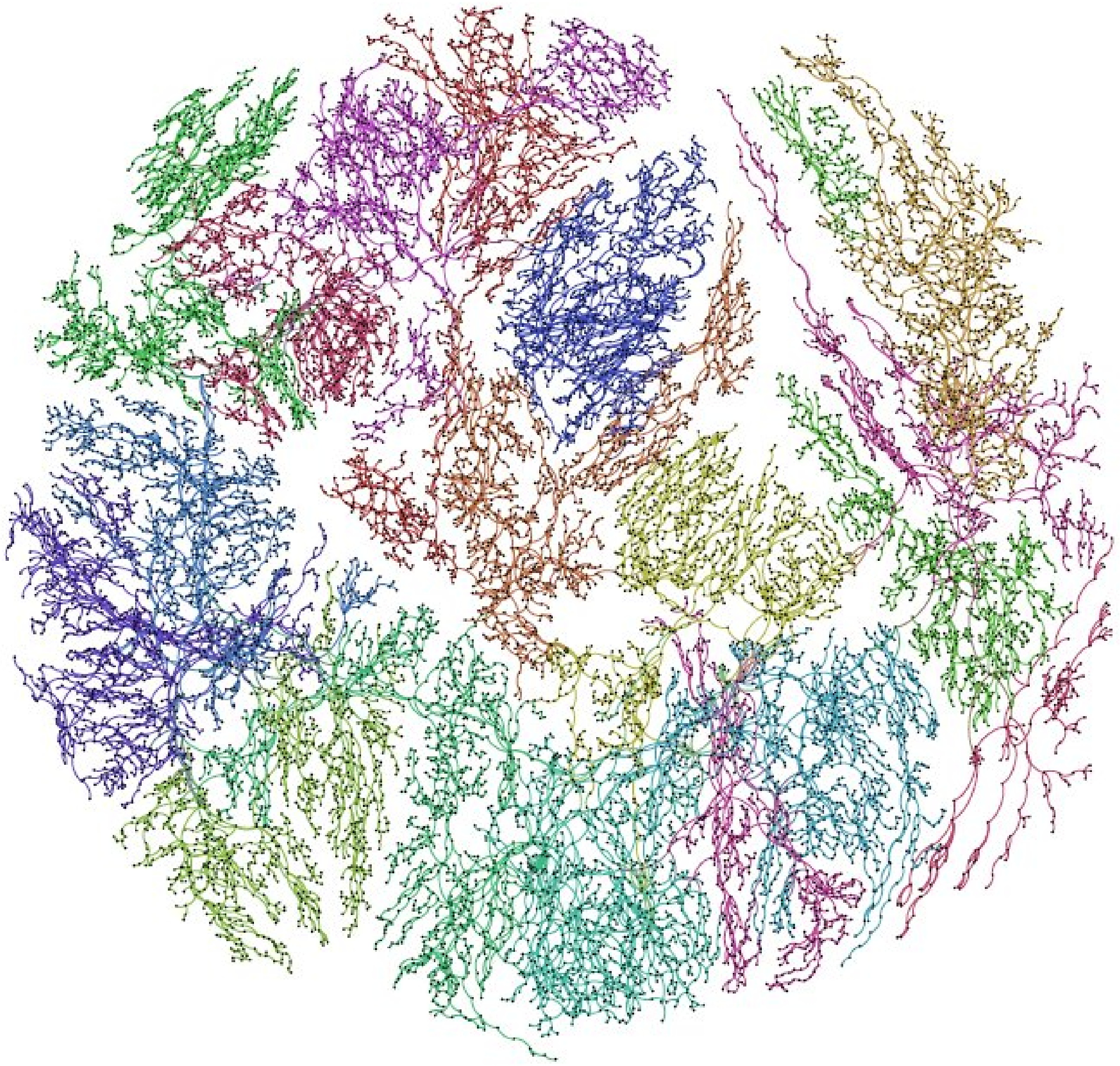
GridPACK^{TM} Approaches

- Create abstractions to hide indexing calculations and communication from application developers
- Promote software reuse by encapsulating functionality
- Simplify usage of advanced libraries
- Create application modules for use in more complicated workflows



Current Status

- Wide variety of solvers and parallel linear algebra available
- Prebuilt modules available
  - Power flow, State estimation, Contingency analysis, Dynamic simulation, Dynamic state estimation
- Robust support for task-based execution
  - Both Windows and Linux
- GridPACK has been used in
  - Other DOE projects in AGM, GMLC, and ECP
  - Academia (Clemson University)
  - Papers based on GridPACK appearing in literature
- Talking to vendors as a platform for HPC prototyping and testing



WECC (Western Electricity Coordinating Council) network partitioned between 16 processors

Application Examples

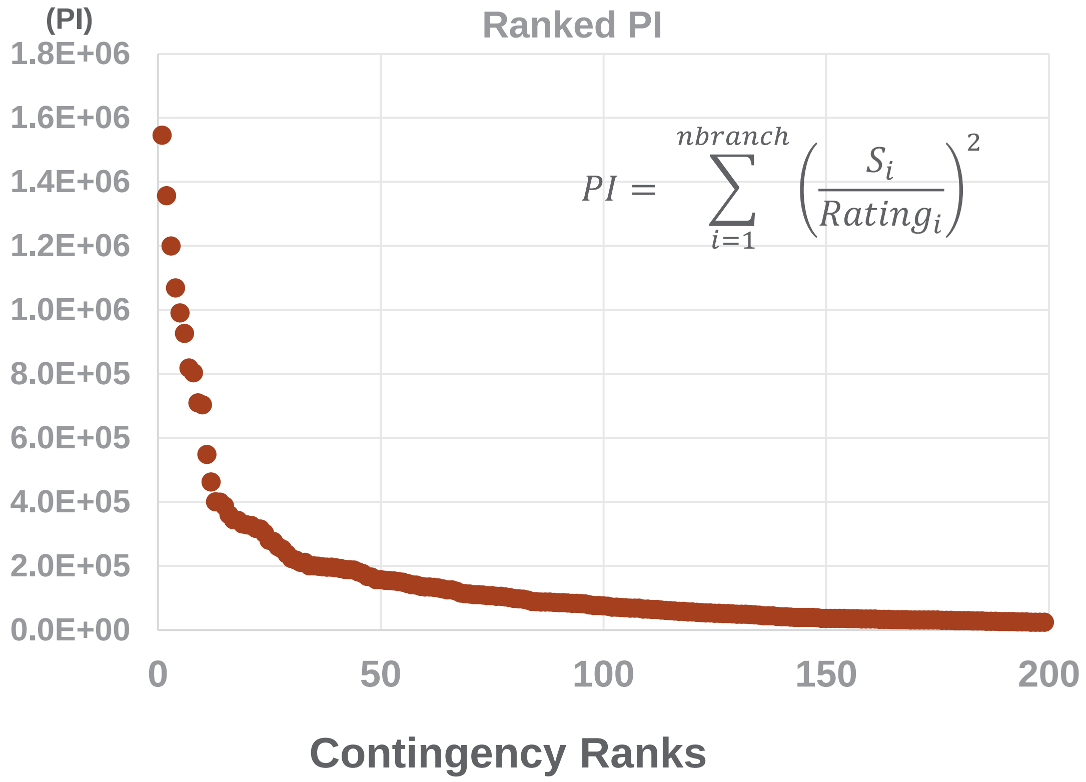
- Contingency Analysis (CA)
- Dynamic Simulation
- Dynamic Security Assessment (DSA) under uncertainty
- Task manager to support Windows-based tools

Example 1: Contingency Analysis (CA)

- Implemented based on GridPACK task manager to assign contingencies to cores based on their availability
- Collect results of separate calculations in a distributed way to help user focus on useful information
  - Performance index for contingency ranking
  - Deviation of power flow from the base case
  - Deviation of bus voltage from the base case
  - Frequency of violations
  - Identify vulnerable portion of the grid

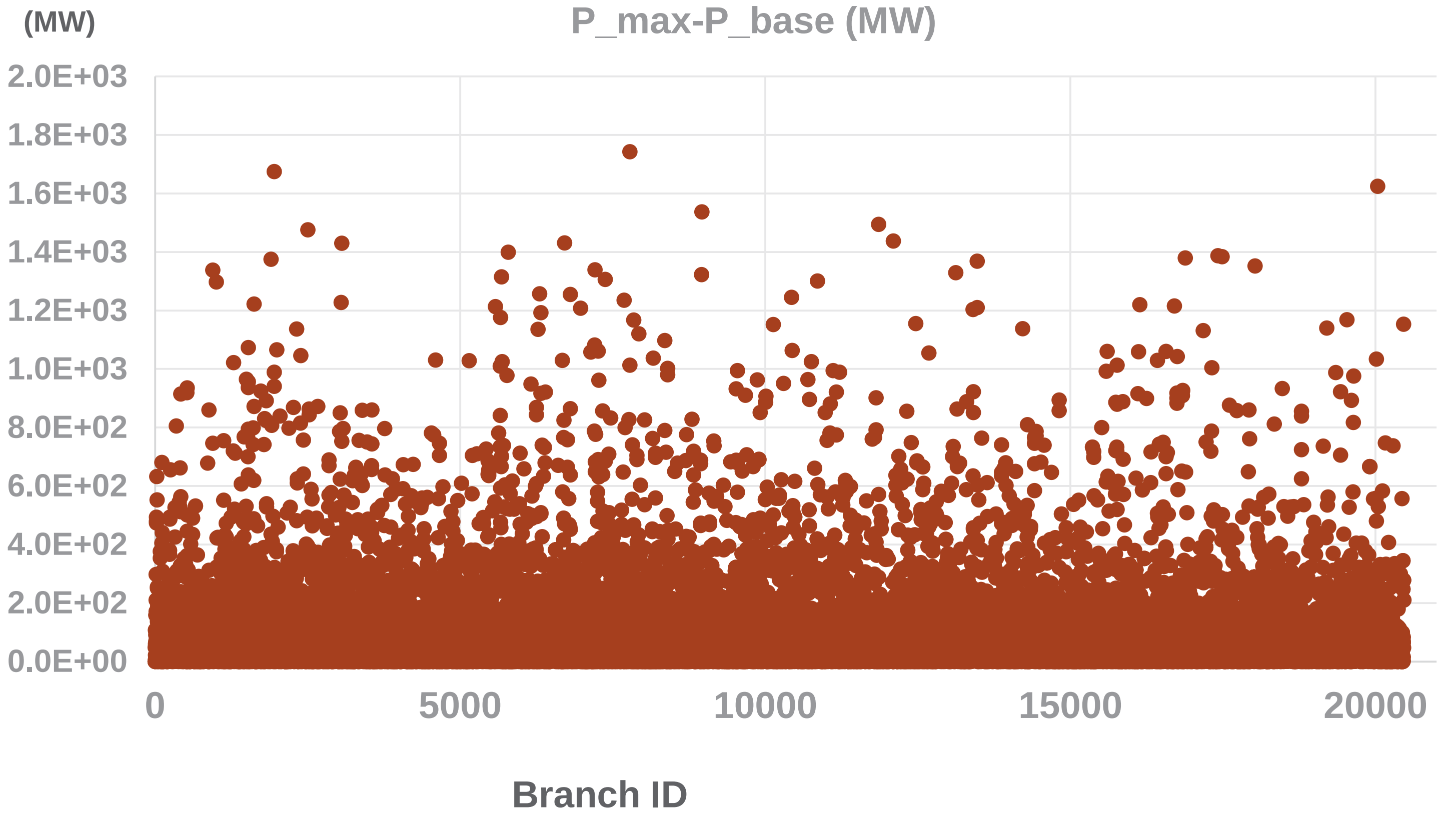
Extract Meaningful Information Out of CA Data

- Contingency ranking based on Performance Index

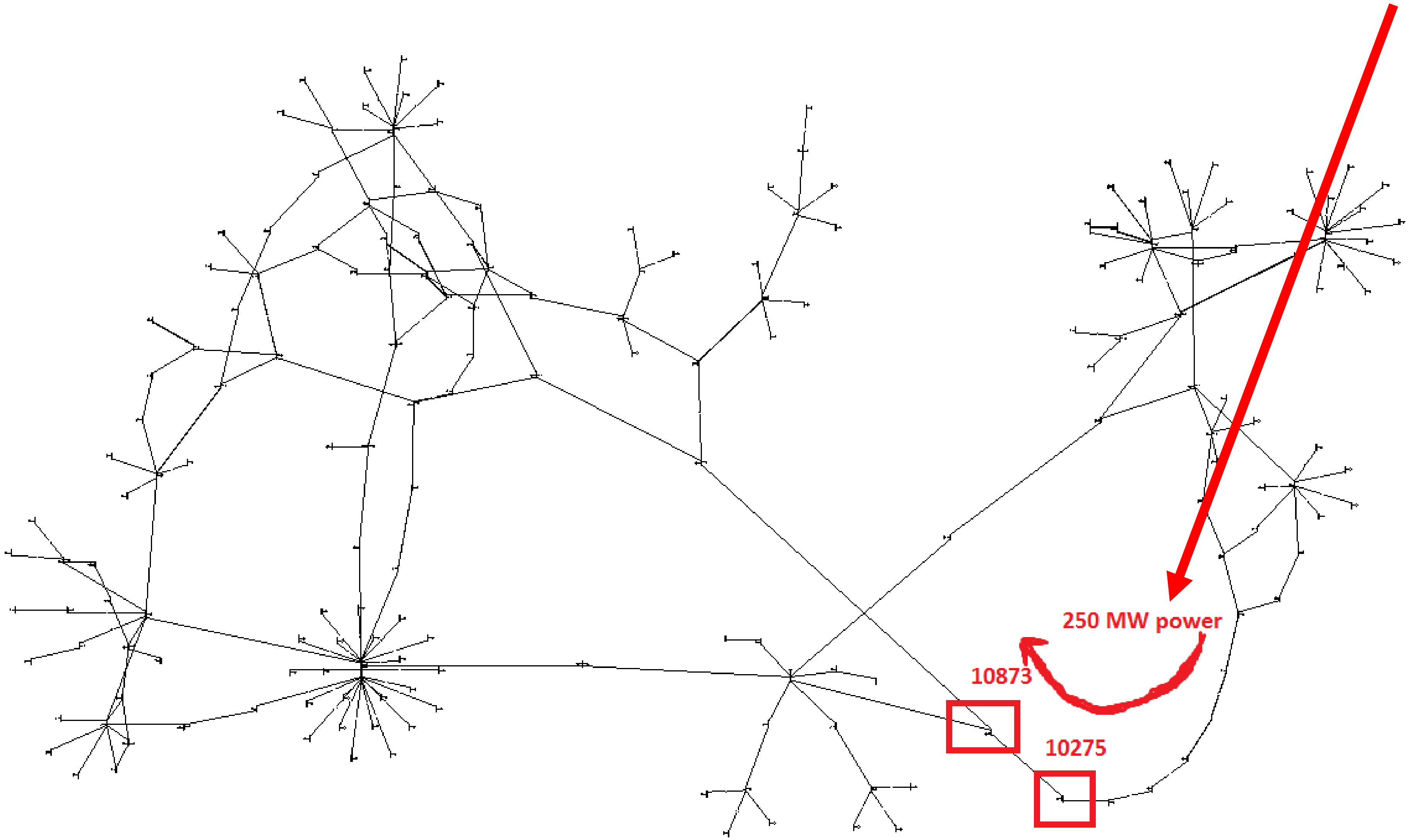


$$PI = \sum_{i=1}^{nbranch} \left(\frac{S_i}{Rating_i} \right)^2$$

- Deviation of maximum real power among all contingencies from base case

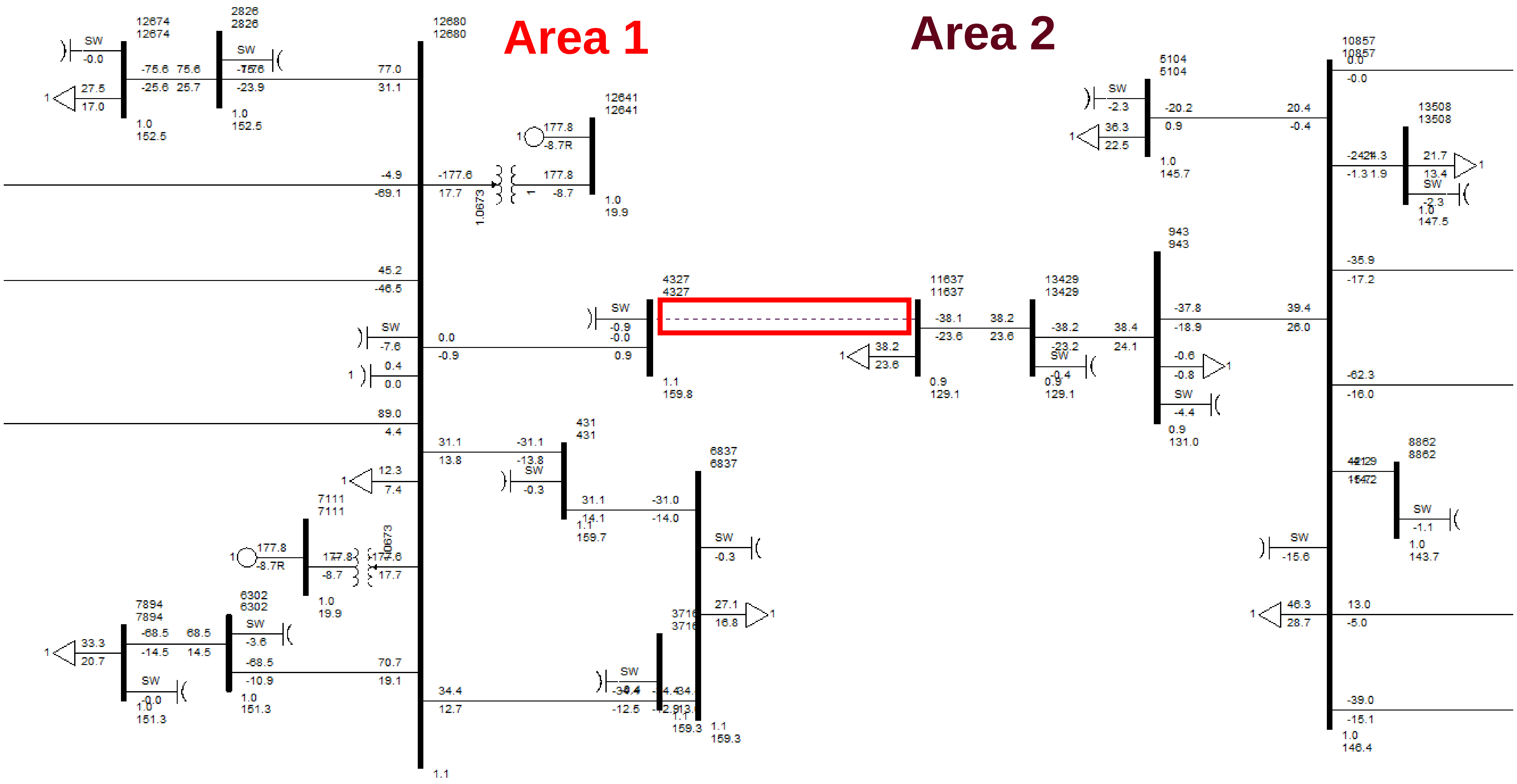


Top Contingency 1



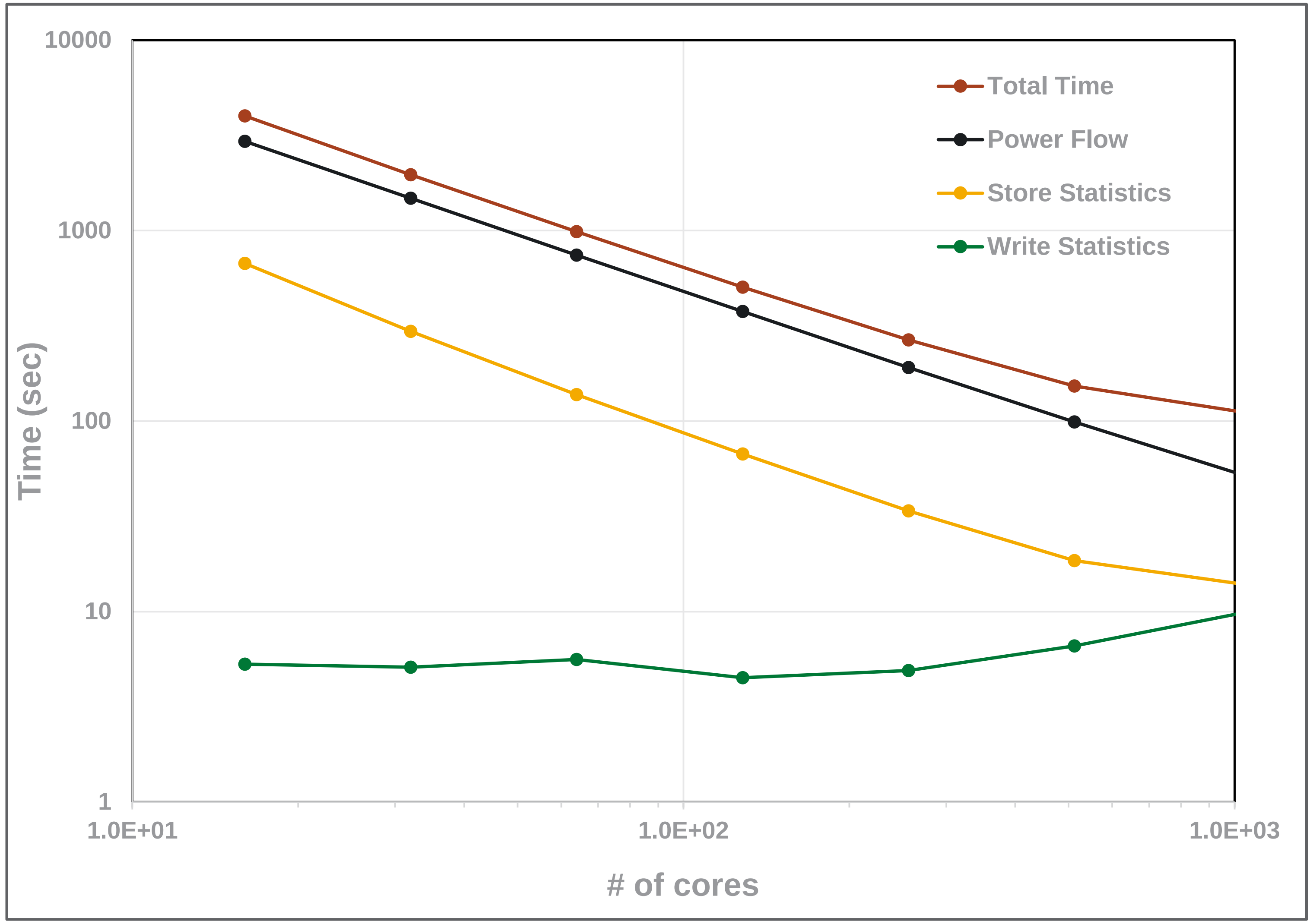
- 250 MW needs to flow through this line if branch connecting buses 10275 and 10873 fails

Top Contingency 2



Computational Performance on CA

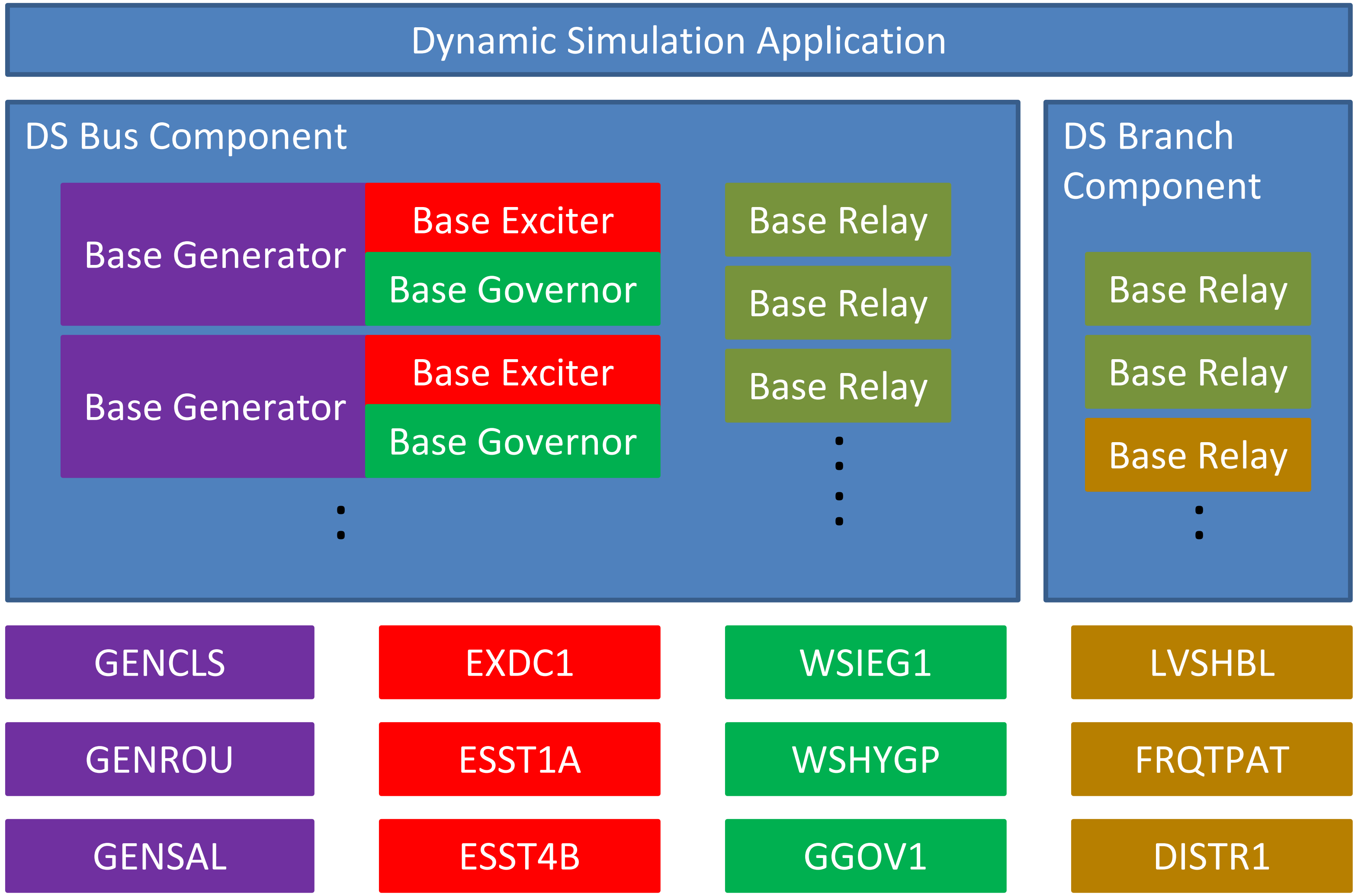
- Test case: open European model with full N-1 branch contingencies (~20K)
- Near linear speedup
- Allow more contingency cases simulated in a shorter time to have a more complete picture
  - Include more low voltage level contingencies
  - Full AC contingency analysis



Simulation time (wall-to-wall) with different number of cores

Example 2: Dynamic Simulation

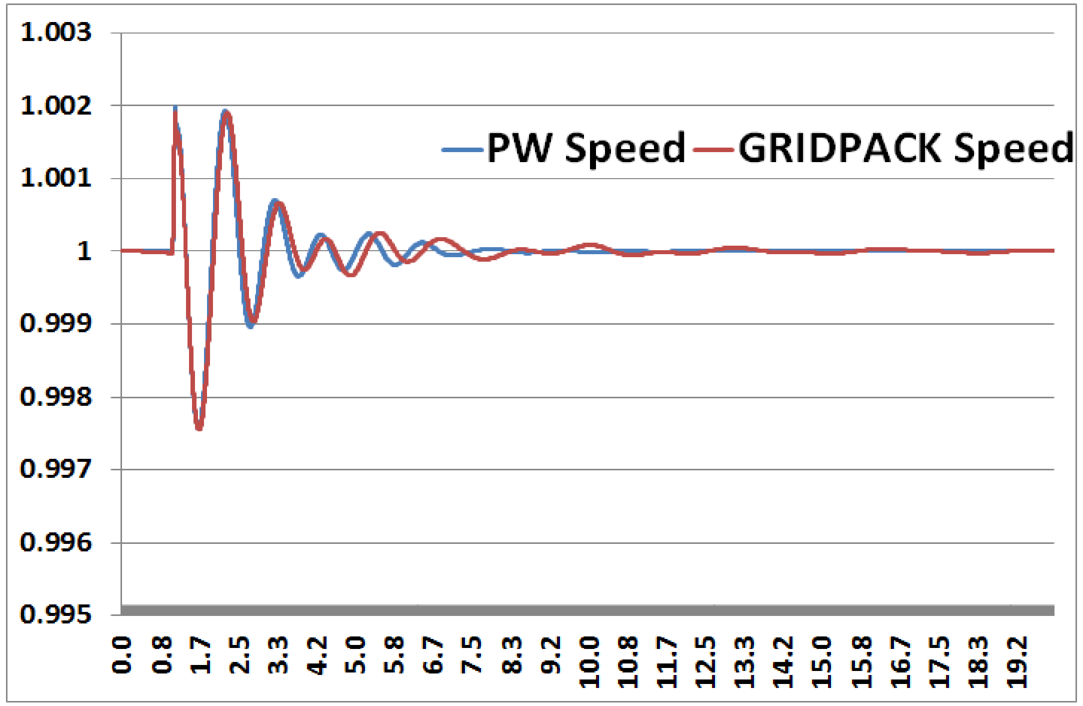
- Core function to perform transient analysis based on Differential Algebraic Equations
- Include detailed dynamic models and relay models
- A time consuming process in today's practise



GridPACK dynamic simulation mini-framework

Dynamic Simulation Performance with Detailed Models

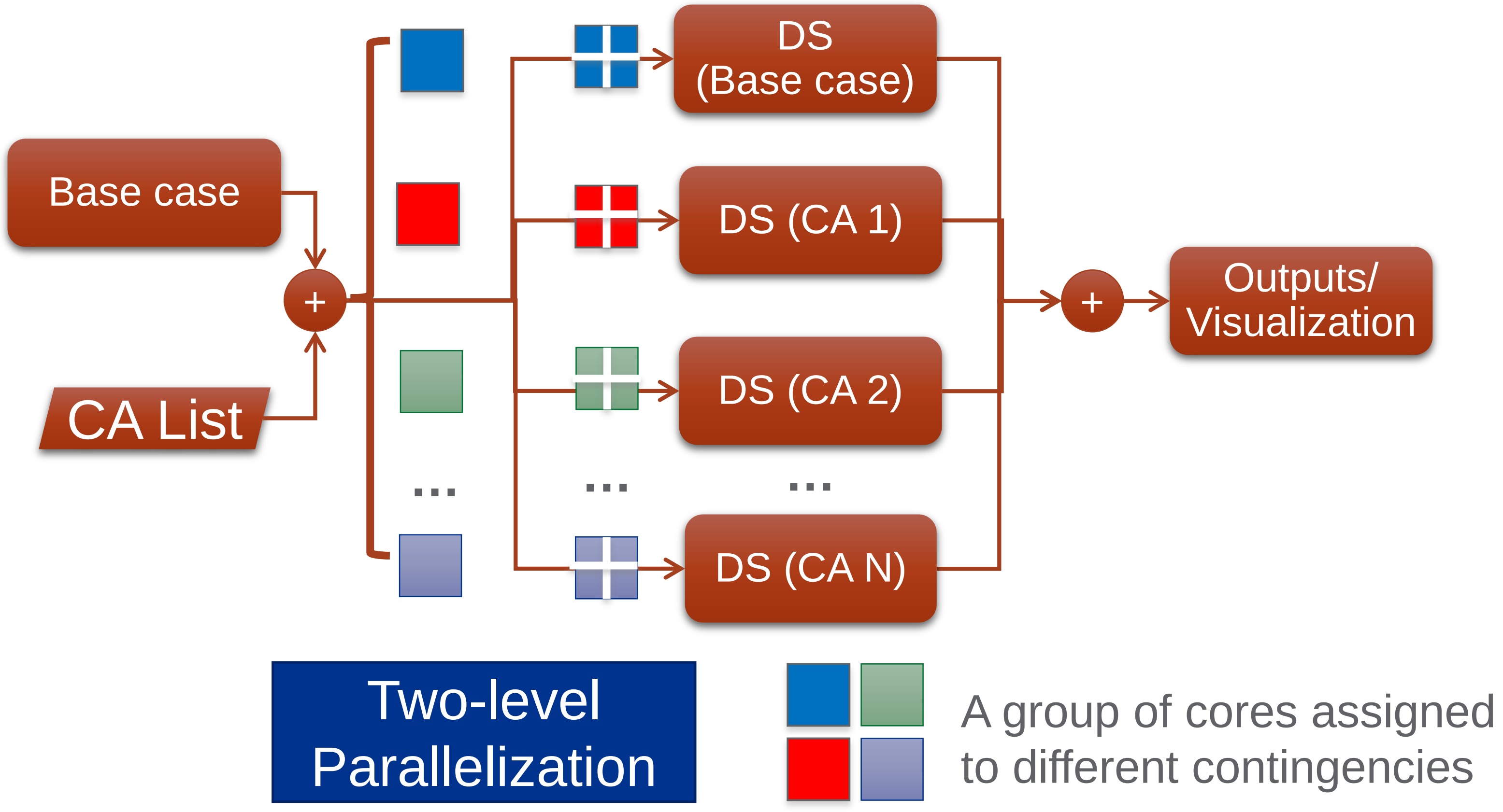
- Simulation details
  - WECC system of 17,000 buses with detailed dynamic models and relay models.
  - 20 seconds simulation, results compared with Powerworld.
- Achieved Faster-than-real-time simulation with 16 cores
  - Powerworld took ~1 minutes (data in memory) (3X faster)



No. of Cores	Total Solution Time (seconds)
1	72.9
2	45.0
4	31.0
8	23.0
16	19.5

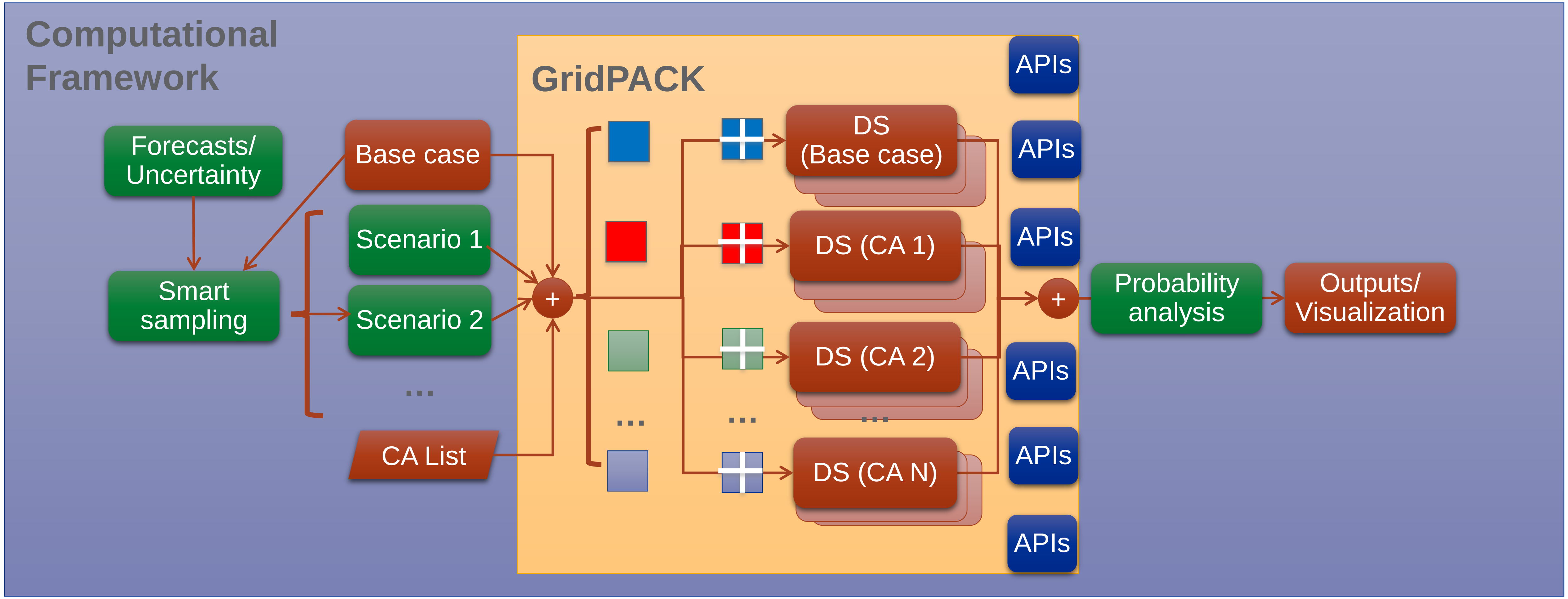
Example 3: Dynamic Security Assessment under Uncertainty (1)

- DSA: Dynamic Simulation (DS) with Contingency
- Two-level parallelization to make full use of computing resources
  - Level 1: Task-based for contingencies
  - Level 2: multiple cores for individual dynamic simulation



Example 3: Dynamic Security Assessment under Uncertainty (2)

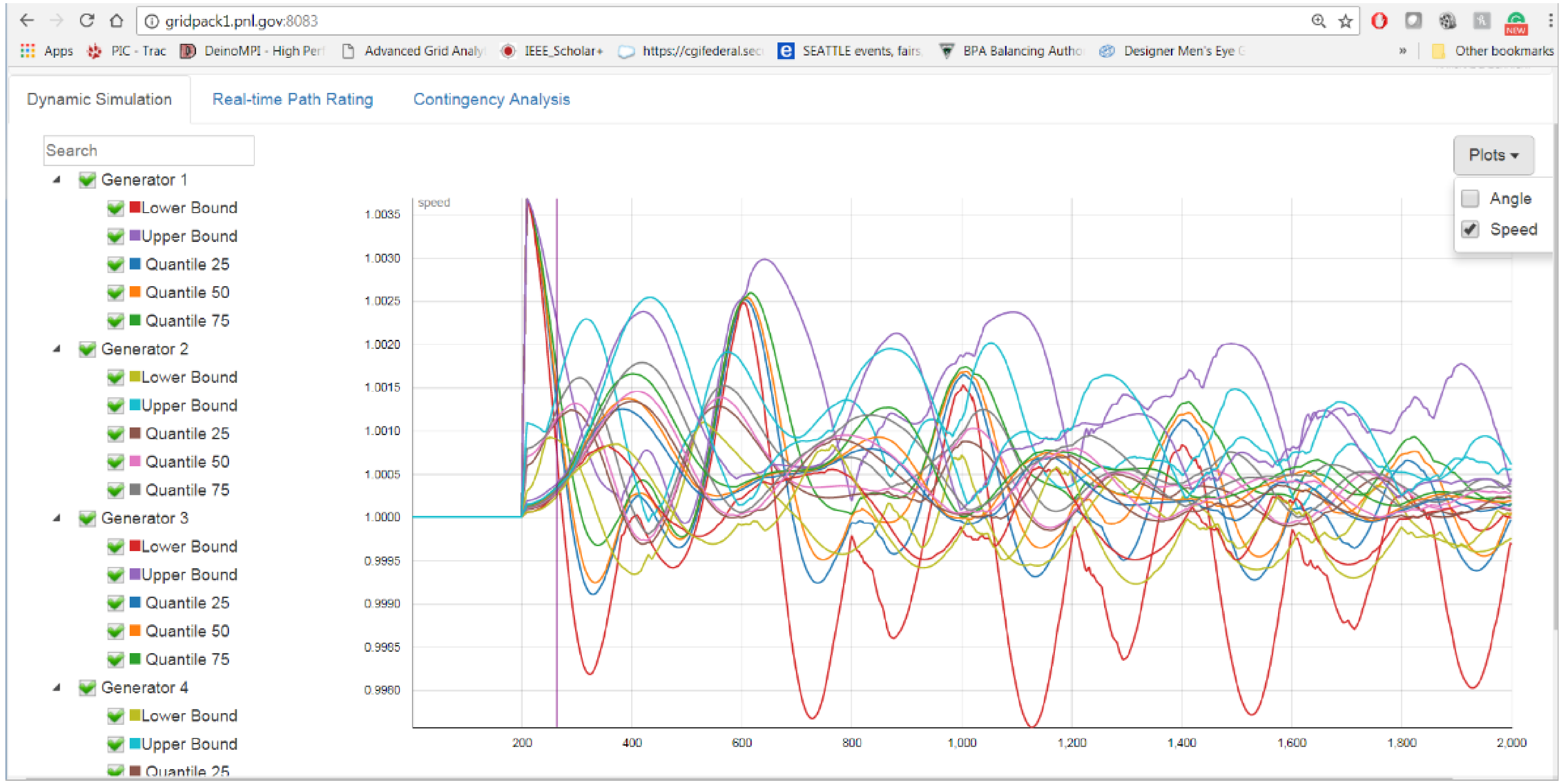
- DSA under uncertainty to address forecast errors under uncertainty
- Need to consider multiple scenarios (more task level parallelization)
- Need a framework to seamlessly like data from different applications



Test Result with the ESCA-60 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



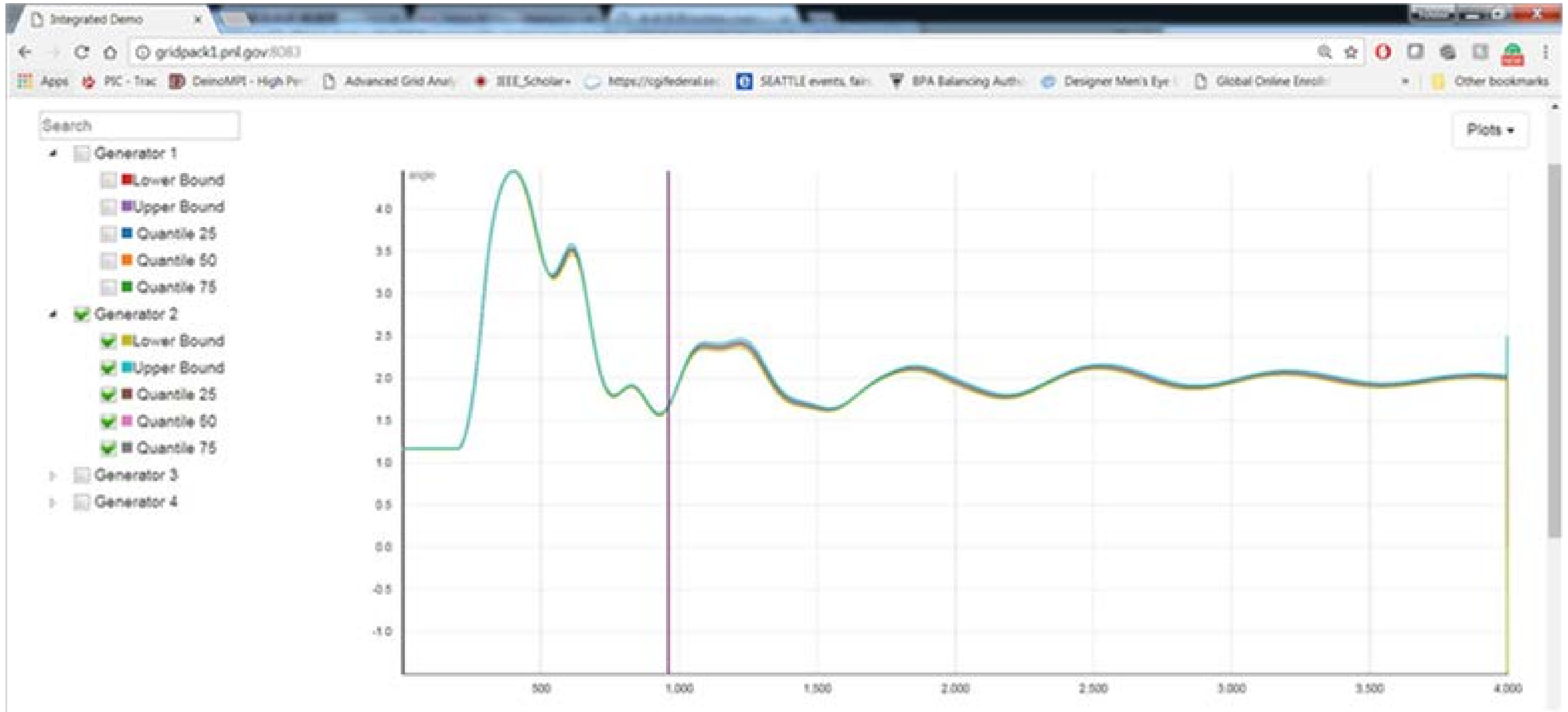
DSA with Uncertainty Test Results using the ESCA-60 System

Test Result with a WECC System

Simulation time (sec)	20
Time step (sec)	0.005
# of scenarios	240
# of contingencies	1
# of cases	240
# of monitored generators	2

# of cores	Time (sec)	Speedup
46	1218	46*
92	652	86
184	340	165
368	182	308

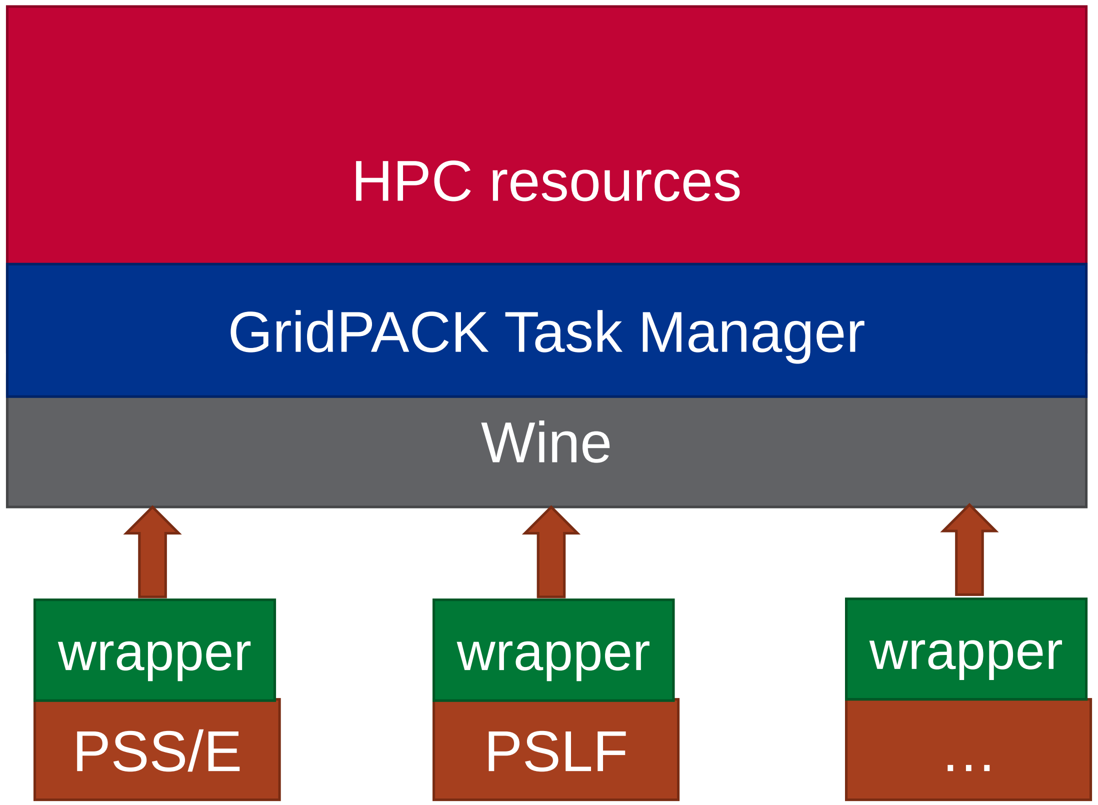
*: assume perfect speedup at 46-core



DSA with Uncertainty Test Results using a WECC System

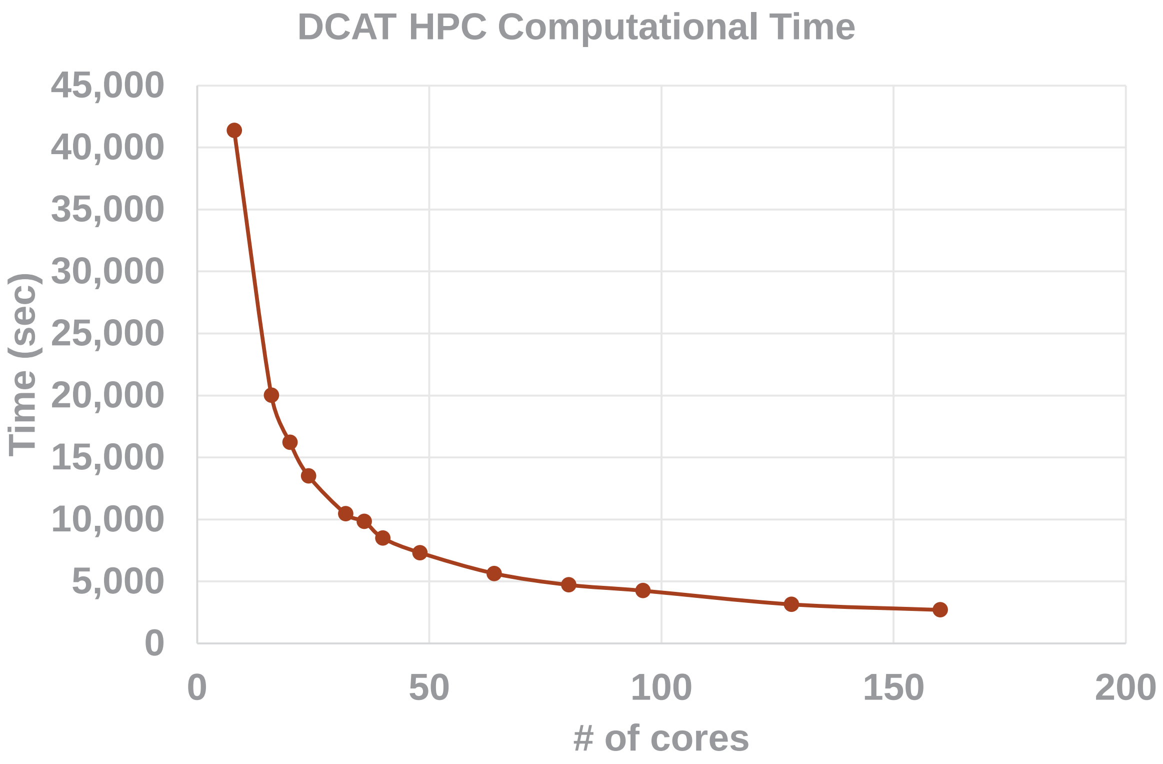
Example 4: GridPACK Task Manager

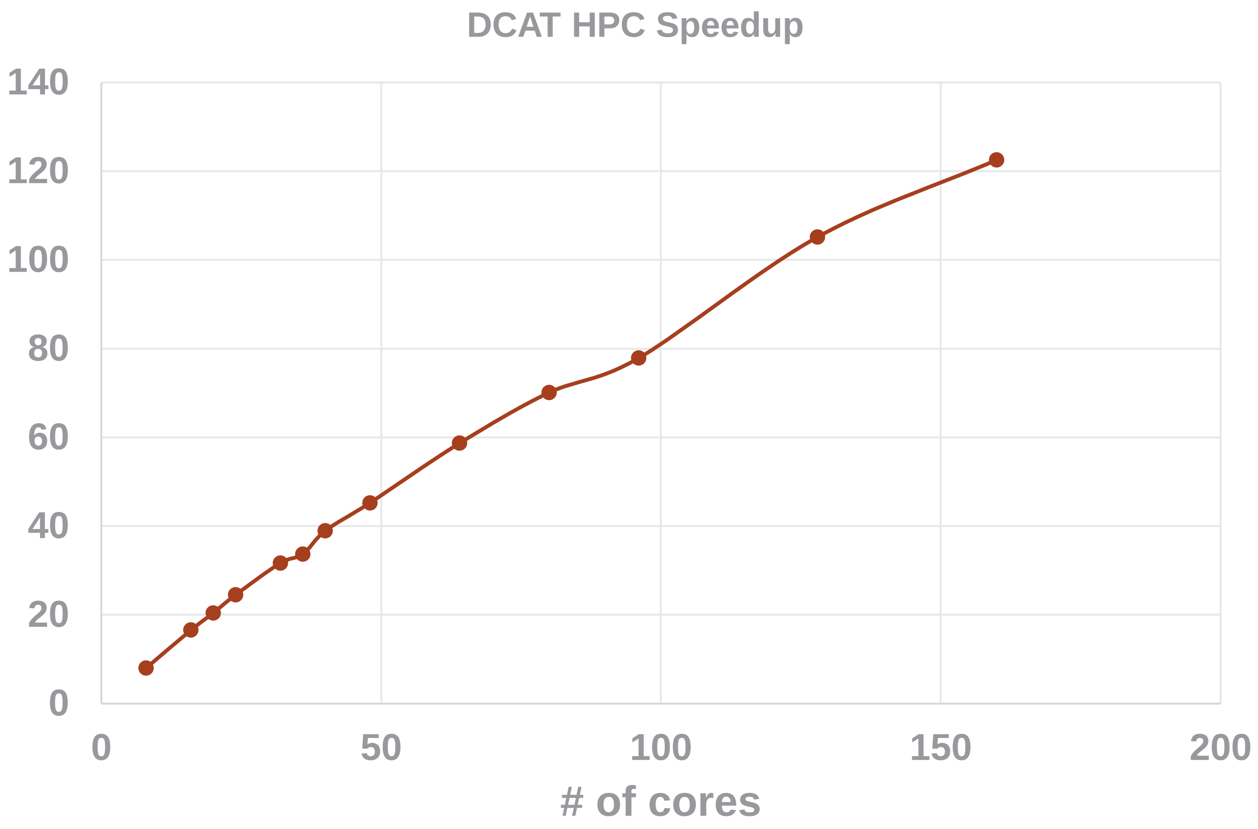
- Create a framework for multi-task simulations capable of executing Windows based tools on Linux-based HPC machines
  - Leverage Wine application
- Being leveraged by Dynamic Contingency Analysis Tool (DCAT) for running PSS/E based simulation on Linux cluster machines
- Generic to be applied to other Windows based simulation tools
  - Breakthrough point to allow Windows based commercial tools access HPC resource



DCAT + GridPACK

- WECC system for 300 cases
  - 4,722 seconds with 80 cores, a speed up of 70 was achieved
    - ✓ 30% reduction comparing against a 80-core Windows server (6,776 seconds)
  - 2,700 seconds with 160 cores





Incorporating Commercial Tools

- Vendors can make software available as a library that can be incorporated as modules to extend GridPACK functionality
  - Enable commercial tools to be integrated with more complex workflows
  - Focus on more efficient data management and analysis
  - Create License Manager for running commercial tools in HPC environment

Conclusions

- GridPACK is a full framework for developing HPC power grid applications
  - Minimize the requirement of HPC programming
  - Provide necessary elements to develop broader and more complicated functions
- Some applications already available for use
  - Powerflow, contingency analysis, dynamic simulation, state estimation, dynamic state estimation
- Performance has been demonstrated with in multiple projects
- Focus on demonstrating value of HPC to power grid community
  - Working with vendors and industry stakeholders
  - Outreach to academic institutions

Acknowledgements and Contacts

- GridPACK is mainly supported by OE Advanced Grid Modeling (AGM) program
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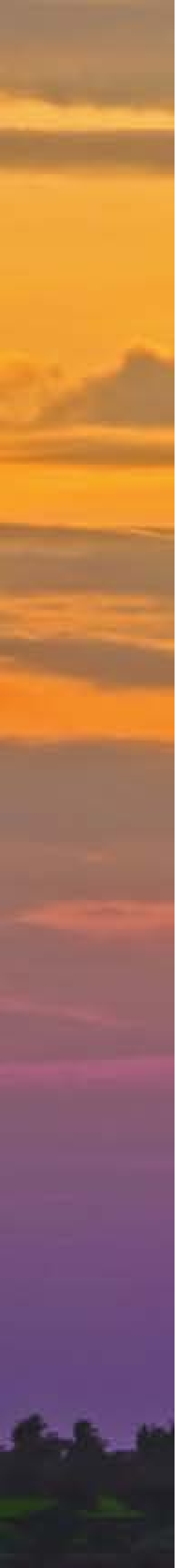
    - ✓ Slaven Peles
  - Power system engineers
    - ✓ Renke Huang
    - ✓ Shrirang Abhyankar
    - ✓ Zhenyu Huang

- Contact: Yousu Chen yousu.chen@pnnl.gov
- Downloads and documentation available at www.gridpack.org.
- Questions and comments to gridpack.account@pnnl.gov.



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Thank you