Real-time Simulation and Preventative Control of Power Blackouts

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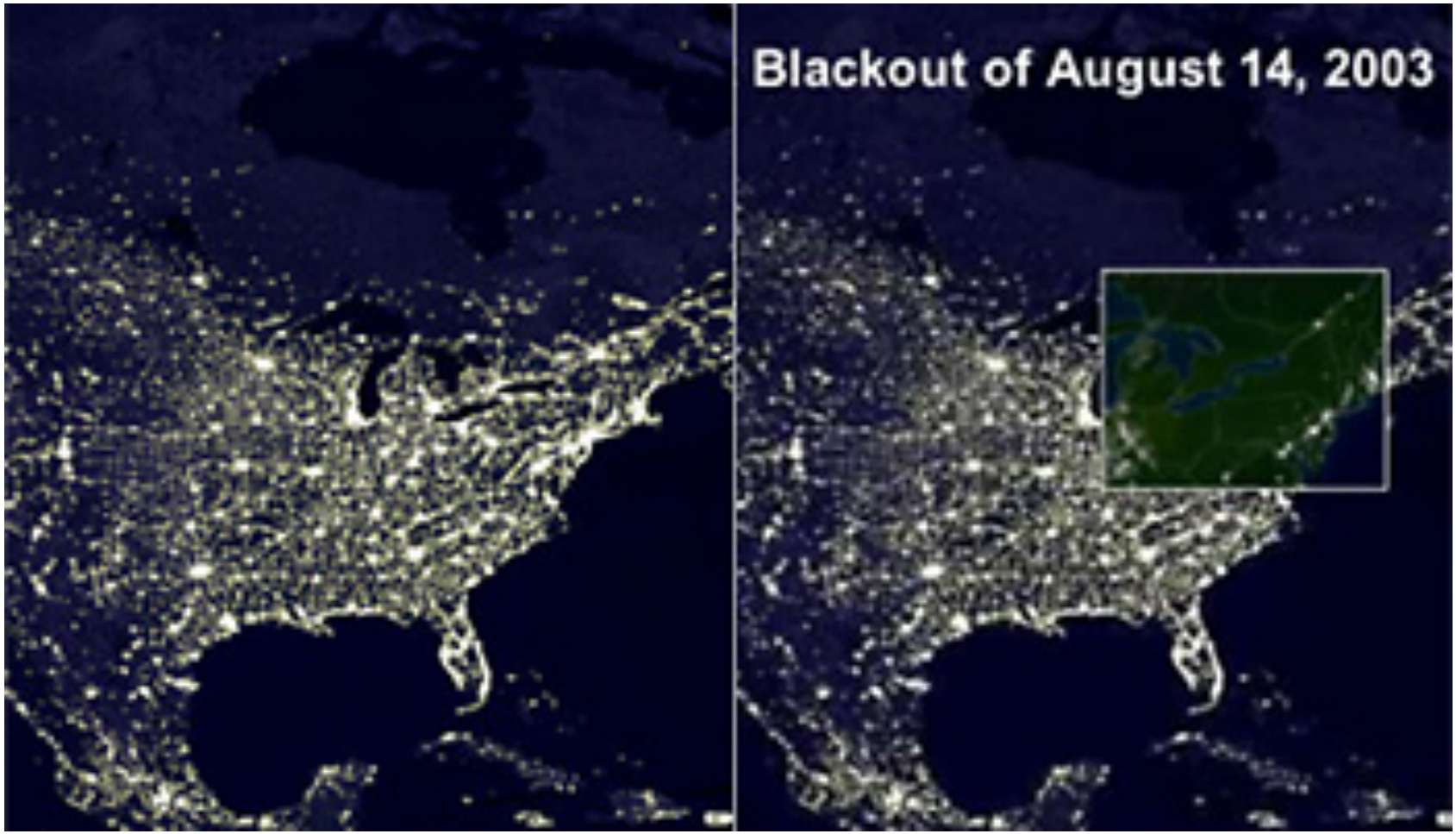
Focus on LARGE Power Blackouts

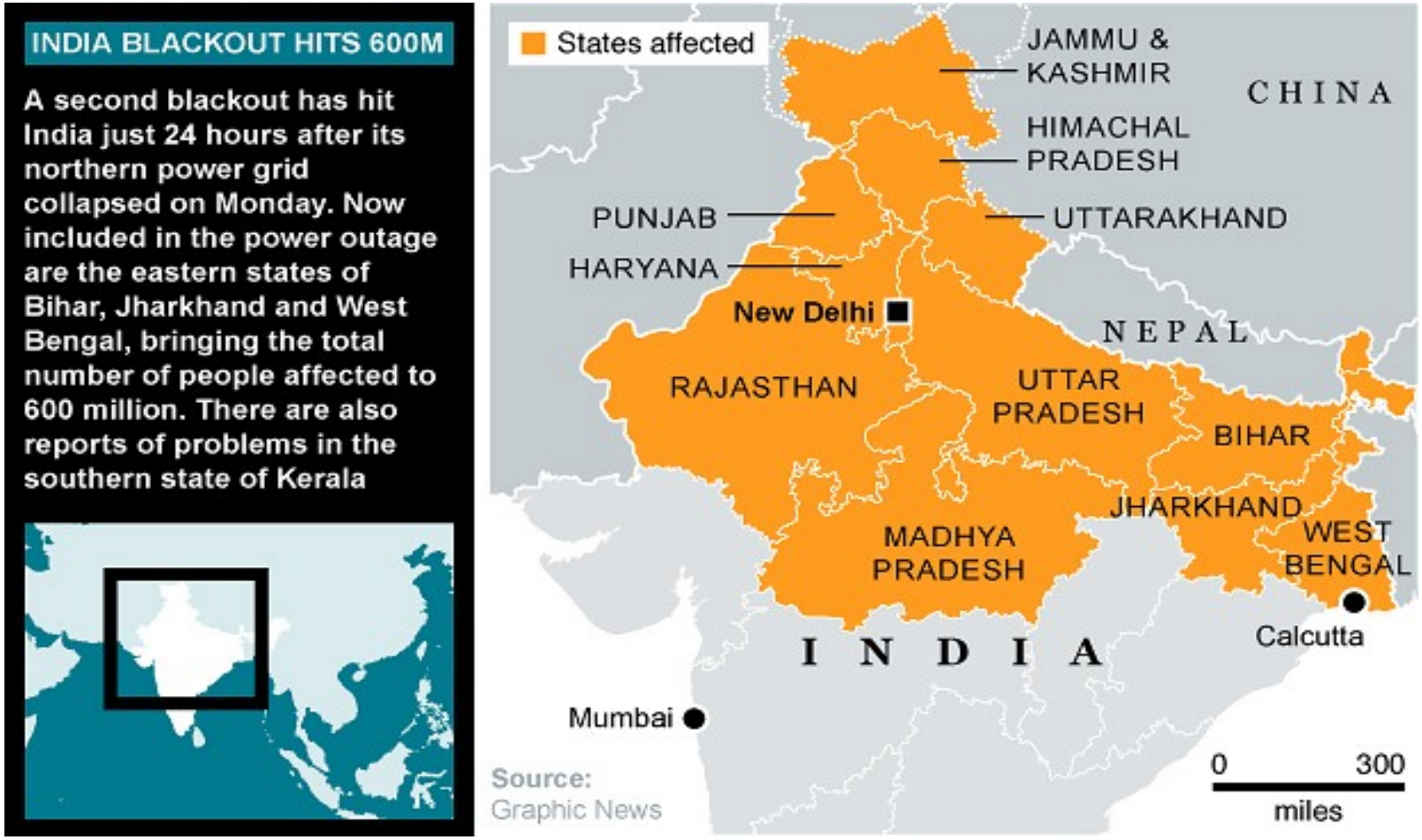


2003 Northeast Blackout affected 55 million people

LARGE Power Blackouts

Southwest Blackout 2011 affected 7 million people

LARGE Power Blackouts



India Blackout 2012 affected 600 million people

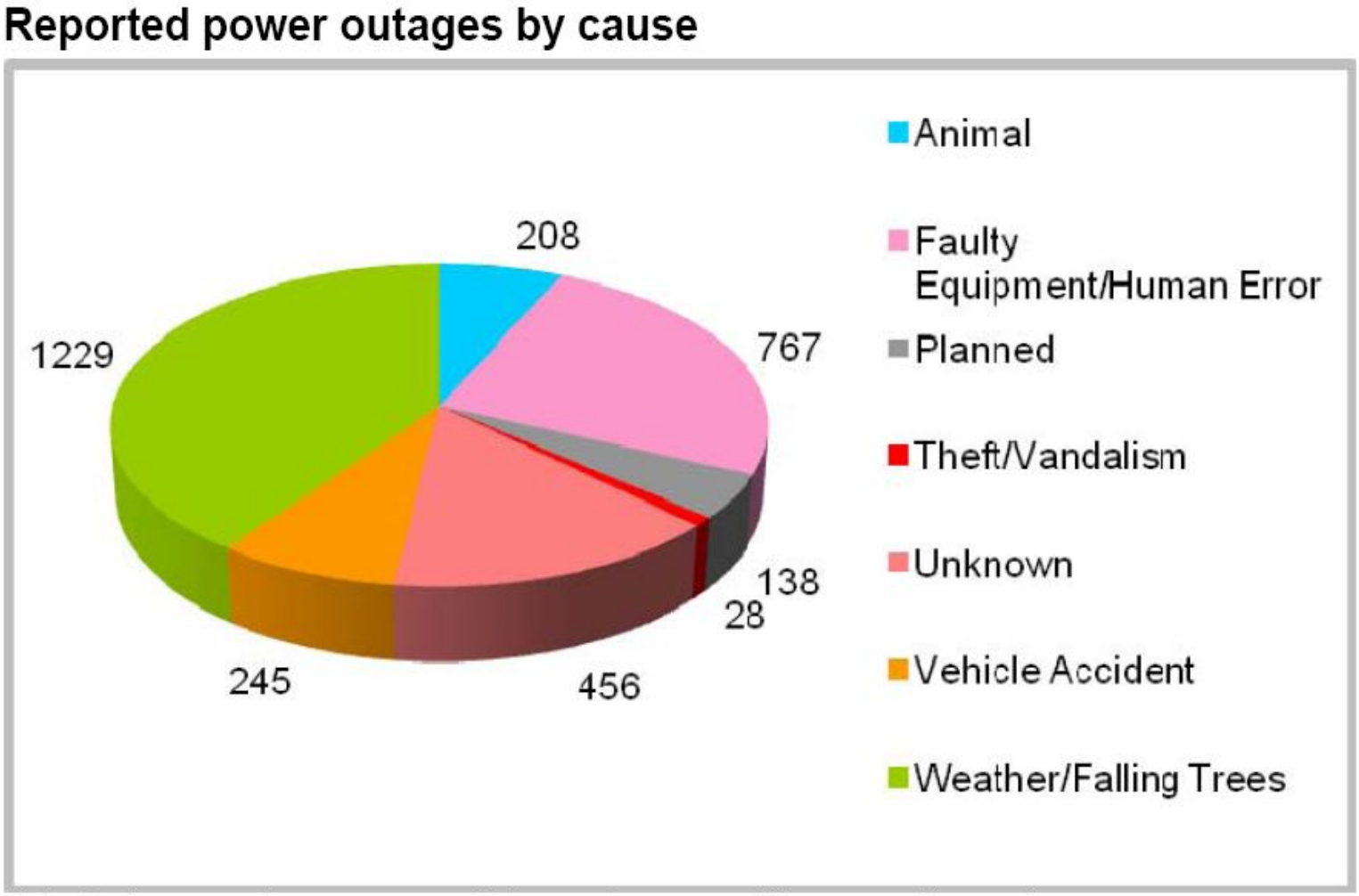
Blackouts are bad

Blackouts are bad

especially when it interrupts a SuperBowl game

Aerial view of the San Diego stadium during the third quarter of the Superbowl Game 2012

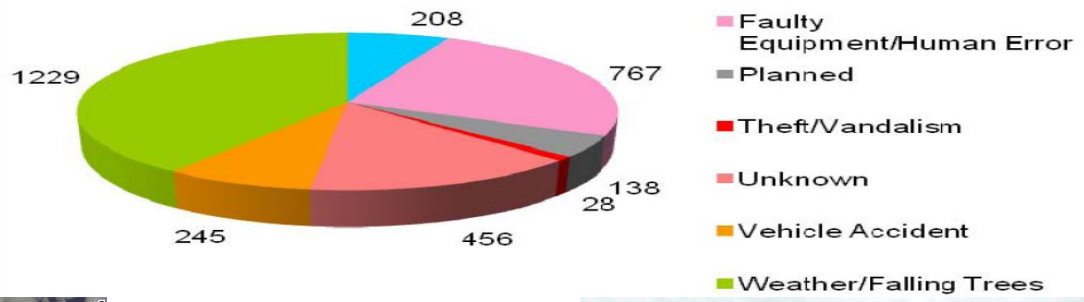
Causes of Power Blackouts



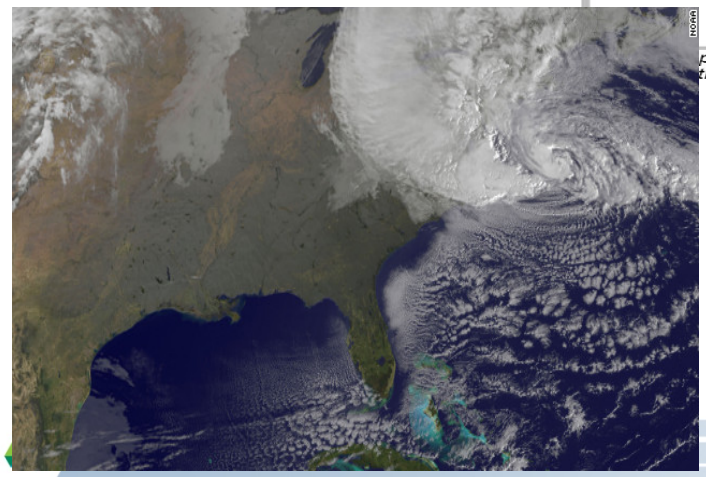
Note: Each power outage was grouped into one of seven possible causes. The number adjacent to the pie piece is the number of outages attributable to that cause.

Causes of Power Blackouts

power outages by cause

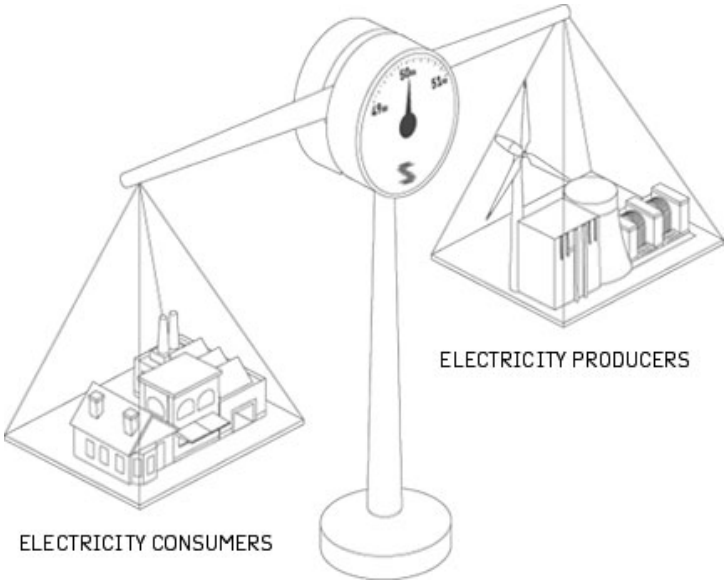


power outage was grouped into one of seven p
the pie piece is the number of outages attributa

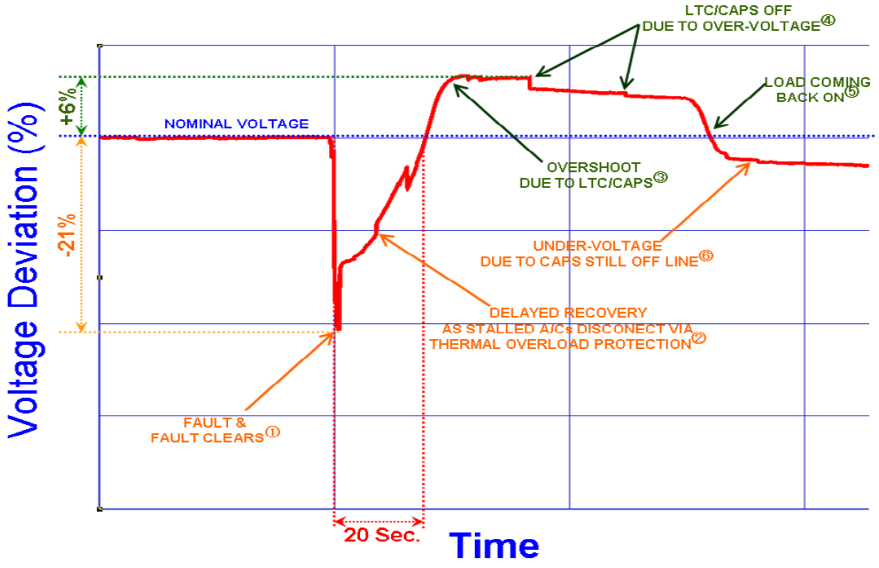


Favorable conditions for blackout

Generation-Load Imbalance



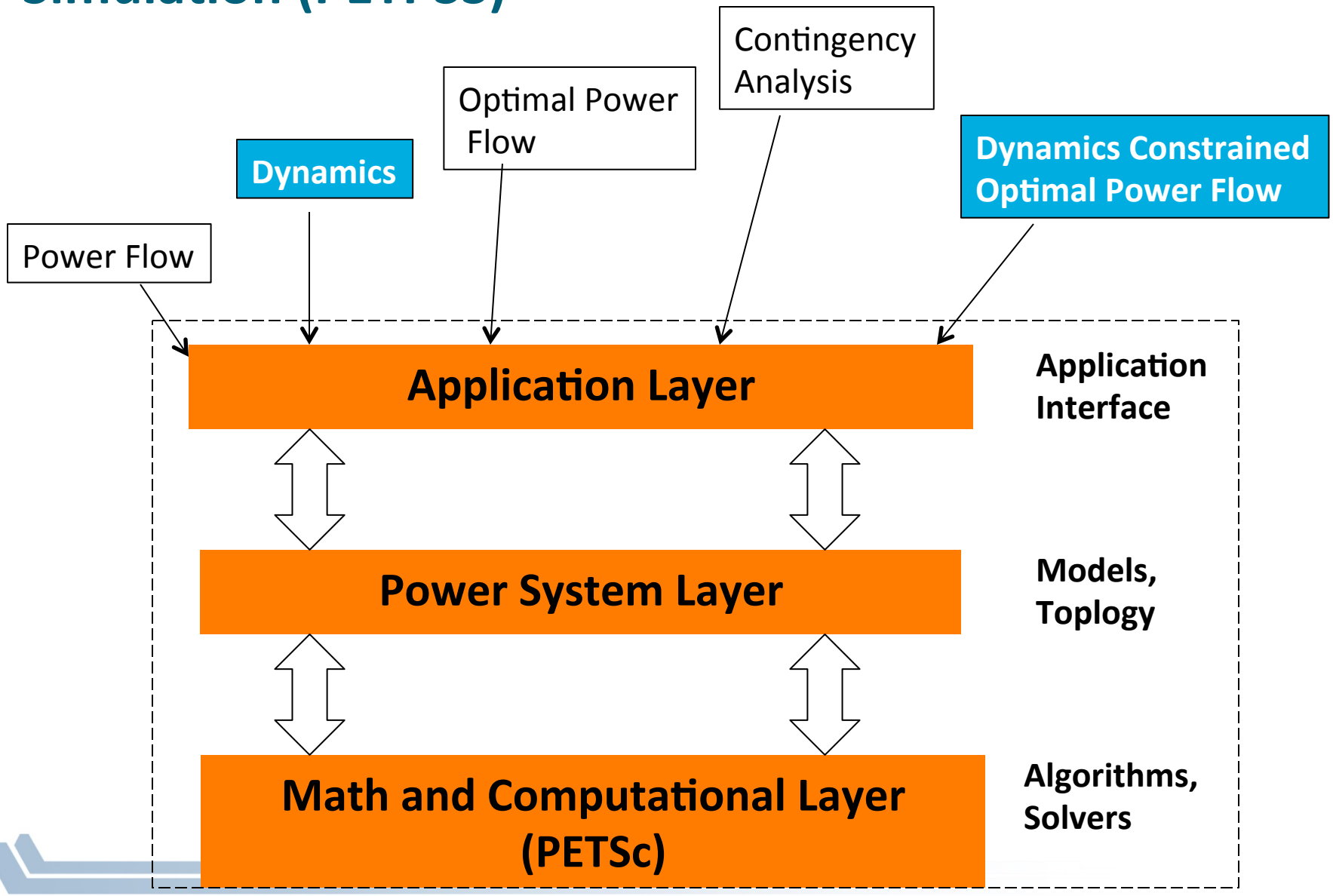
Abnormal voltages



Power System Simulation Research Thrust Areas

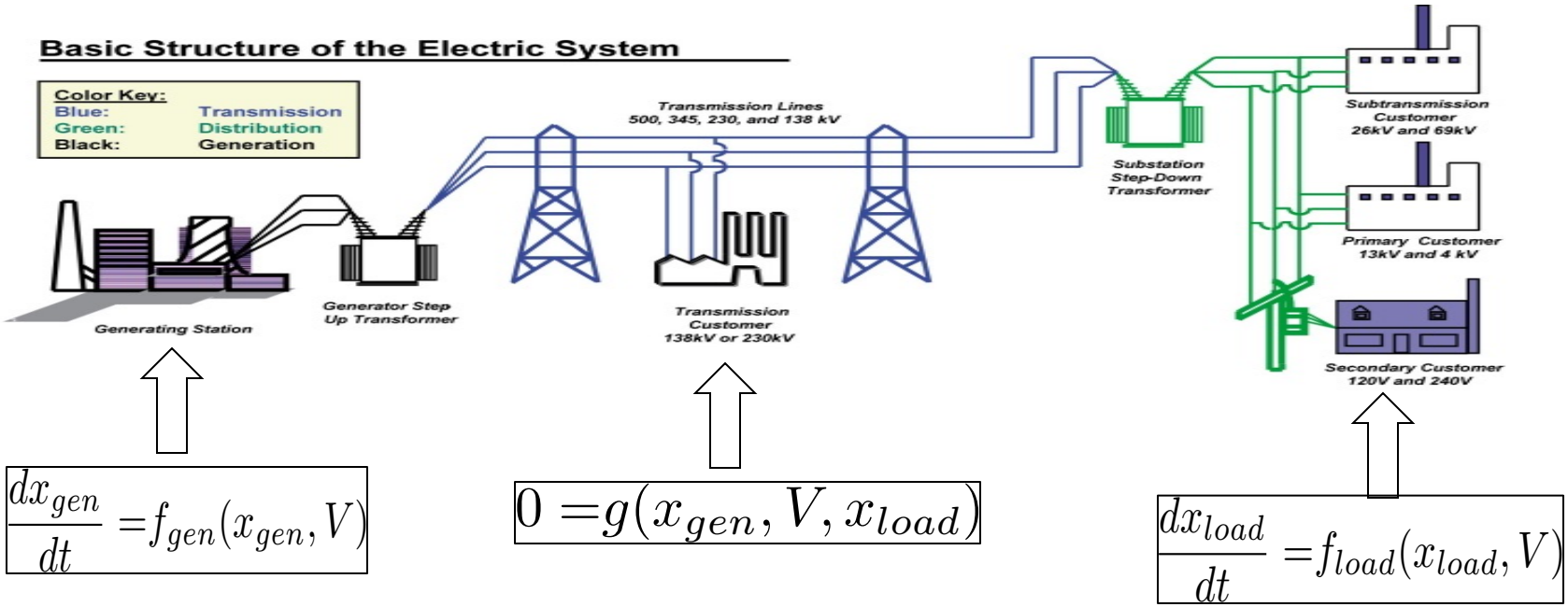
- Parallel Extensible Toolkit for Power System Simulation (PETPSS)
- Simulation of Power blackouts
  - Modeling and solver difficulties
  - Achieving Real-Time or Faster-than-Real-Time Simulation Speed.
  - Preventative control

Parallel Extensible Toolkit for Power System Simulation (PETPSS)



Simulation of large power blackouts

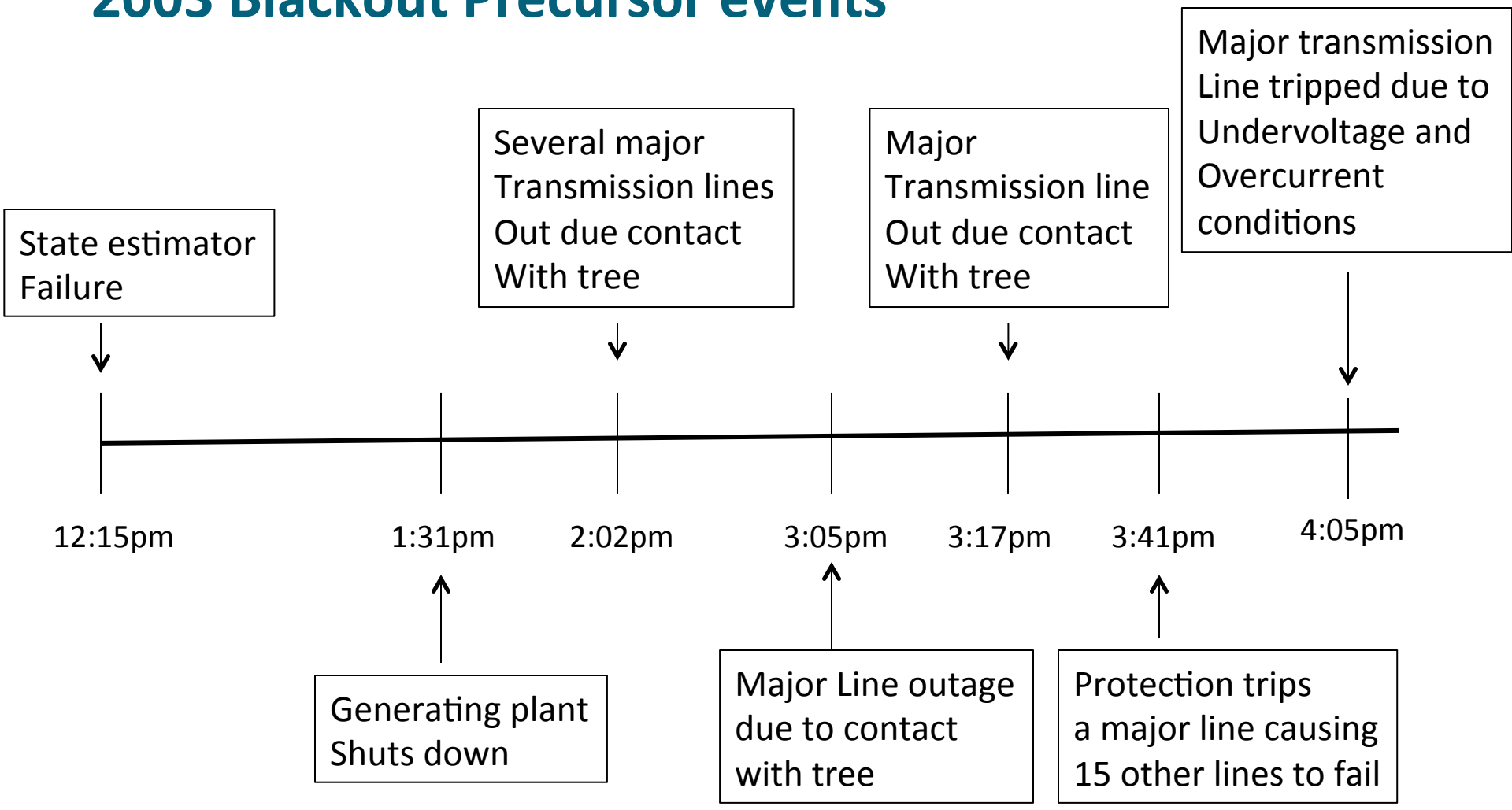
- Simulate short time-frame (seconds to minutes) trajectories (dynamics)



Solution of this Differential-Algebraic (DAE) system needs

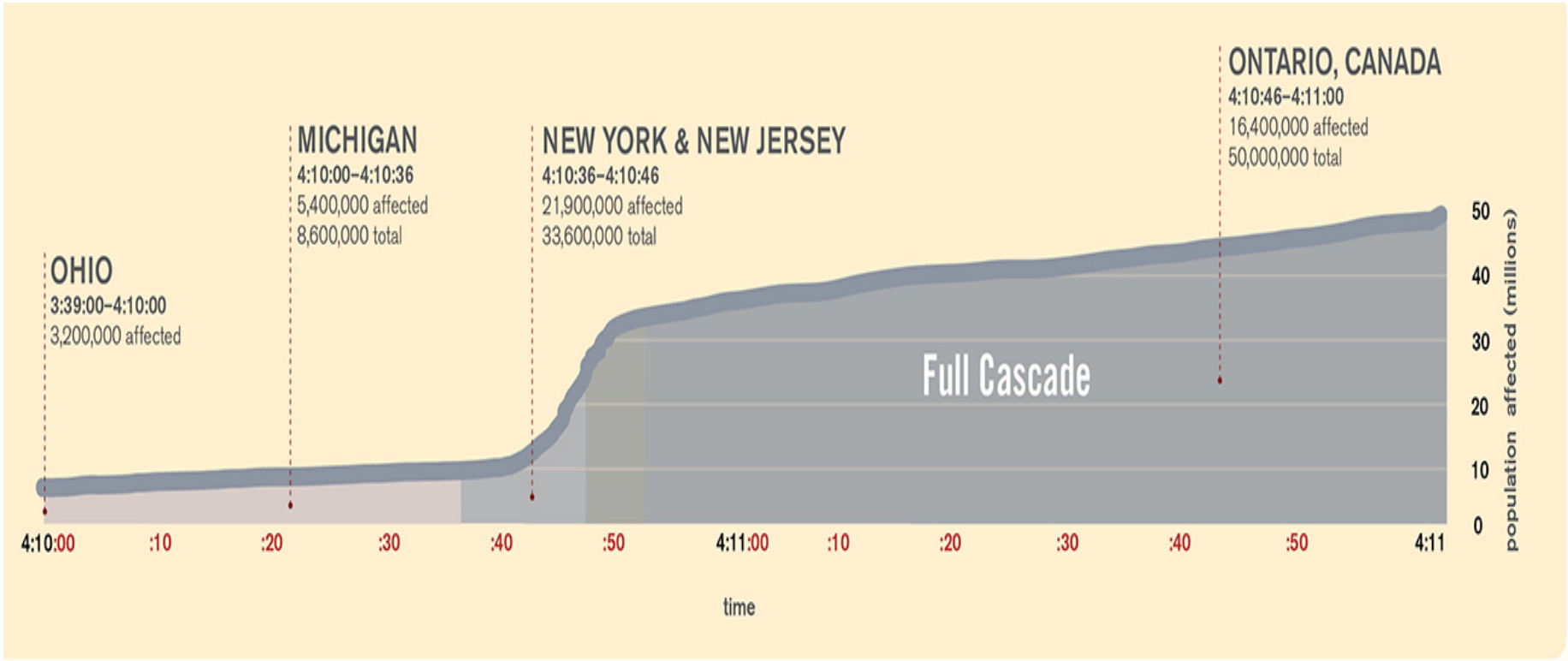
1. **Time-stepping Integrator**
2. **Nonlinear solver**
3. **Linear solver**

Modeling and Solver Difficulties
2003 Blackout Precursor events

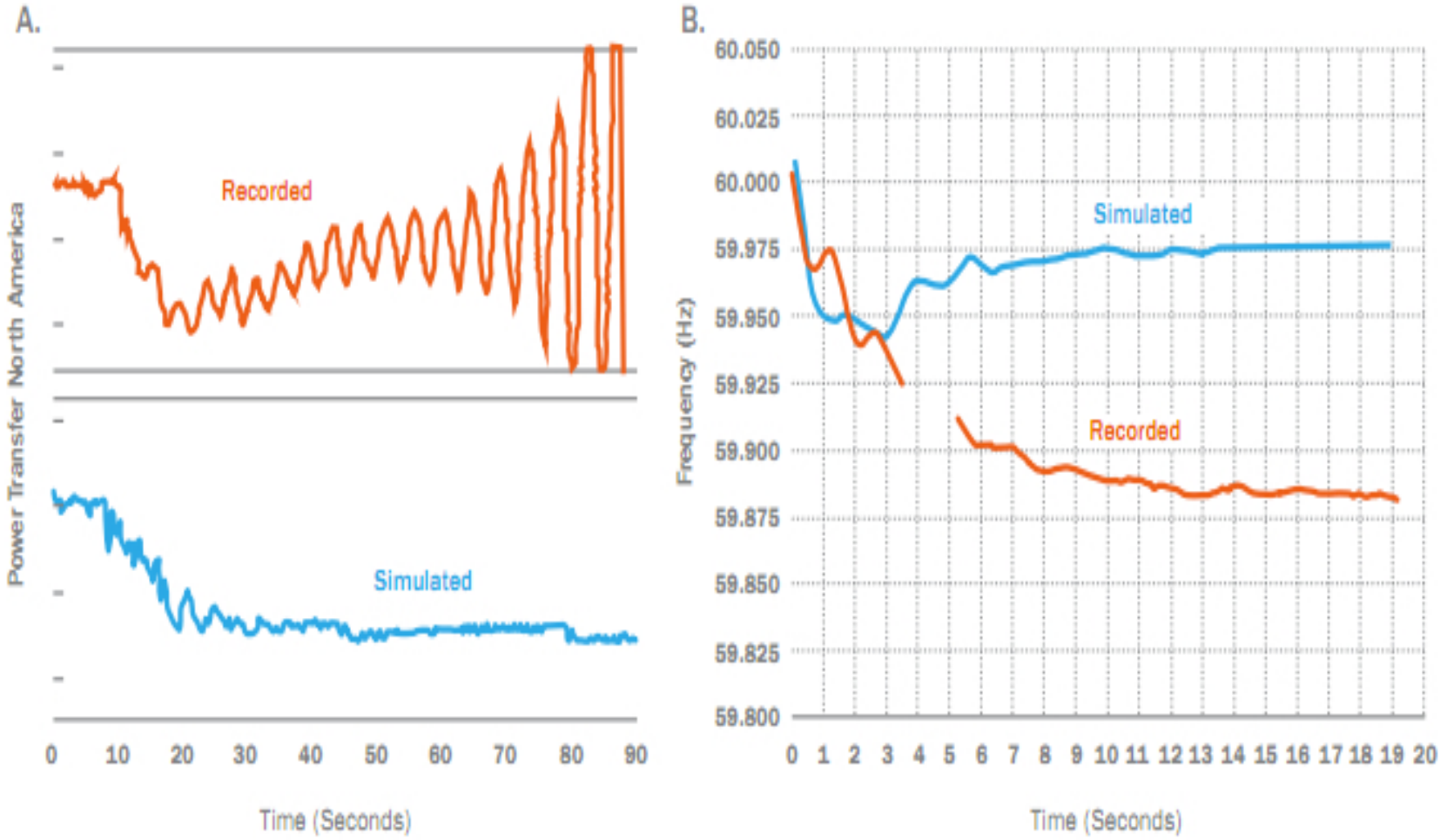


Modeling and Solver Difficulties

Capturing dominos as they fall

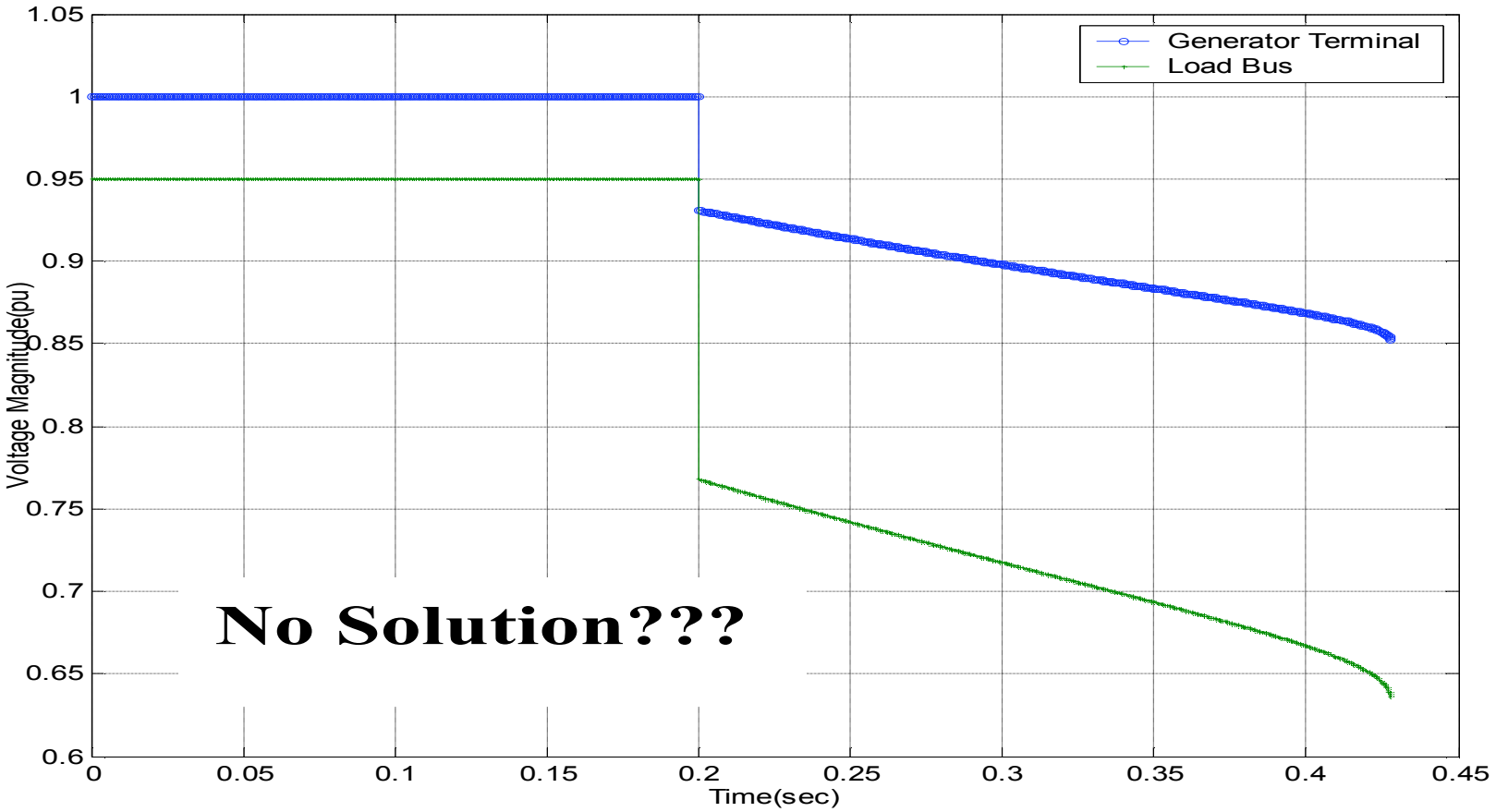


Modeling and Solver Difficulties



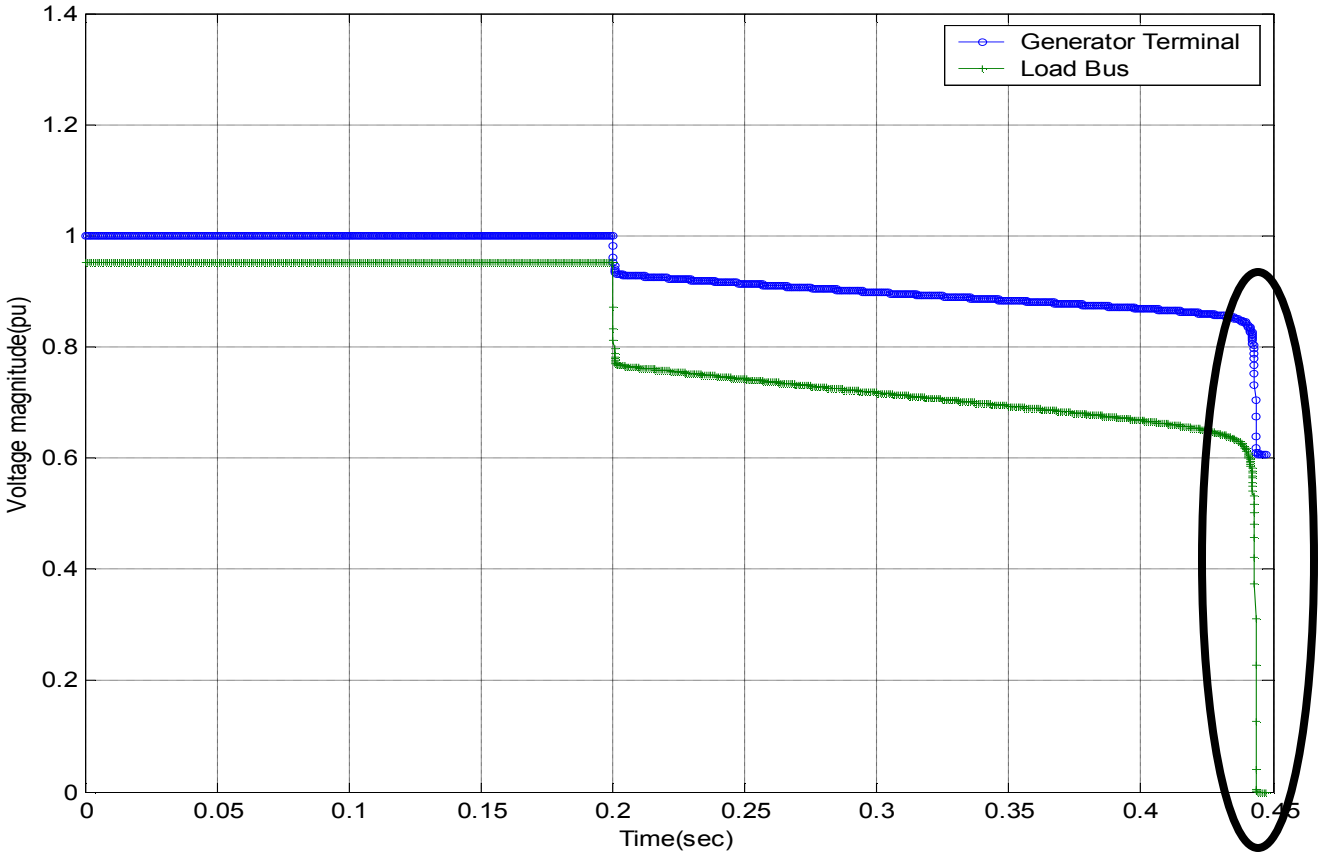
2003 NE Blackout Simulation
Simulated versus Recorded

Modeling and Solver Difficulties



Is this leading to a blackout?

Alleviating solver difficulties



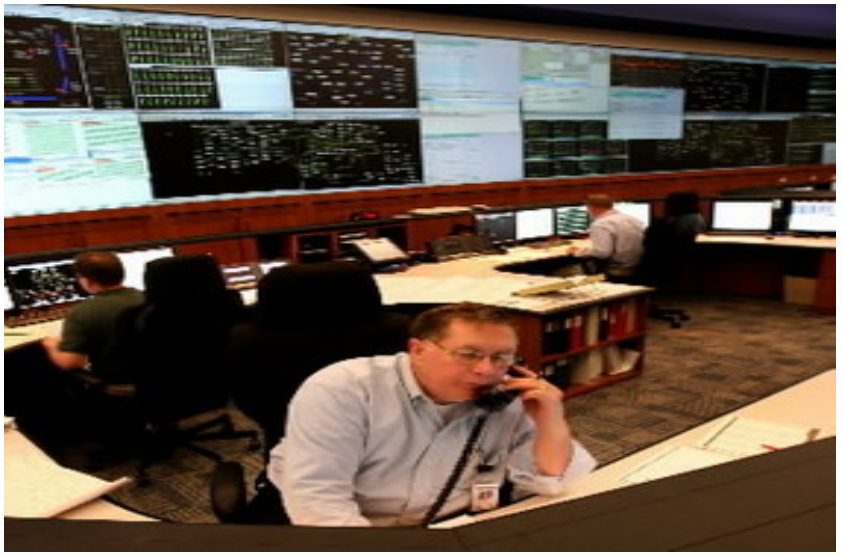
Voltage collapse trajectory

Improved load modeling

$$P_n = P_0 \left(\frac{V_n}{V_{n-s}} \right)^2$$

Real-time Blackout simulations

- What's the need?
  - Assist operators to assess dynamics in real-time when events are evolving.
- Issue: Such simulations are **too slow (not real-time speed)**

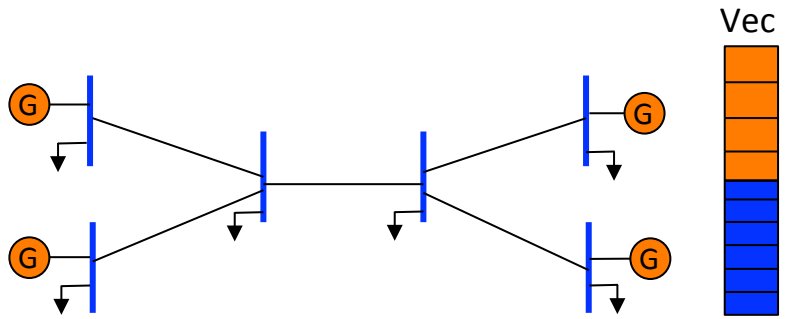


Transmission system control center

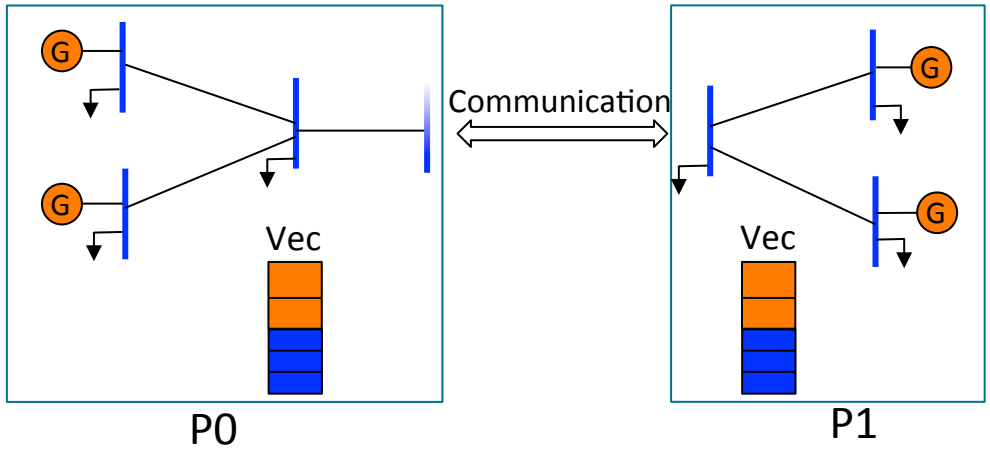
Achieving Real-Time Dynamic Simulation Speed: 1. Parallelization

Multiple processors (cores) used for solving the problem

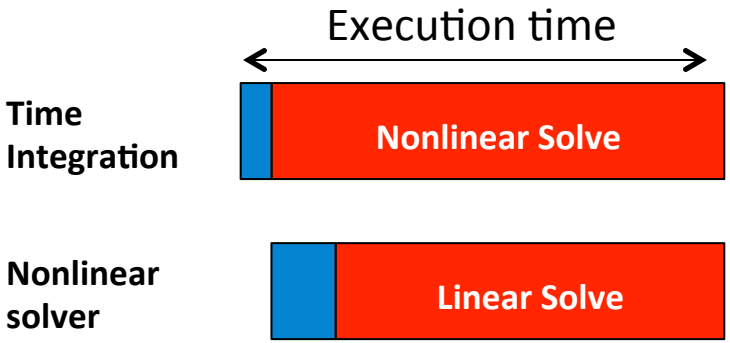
Single processor



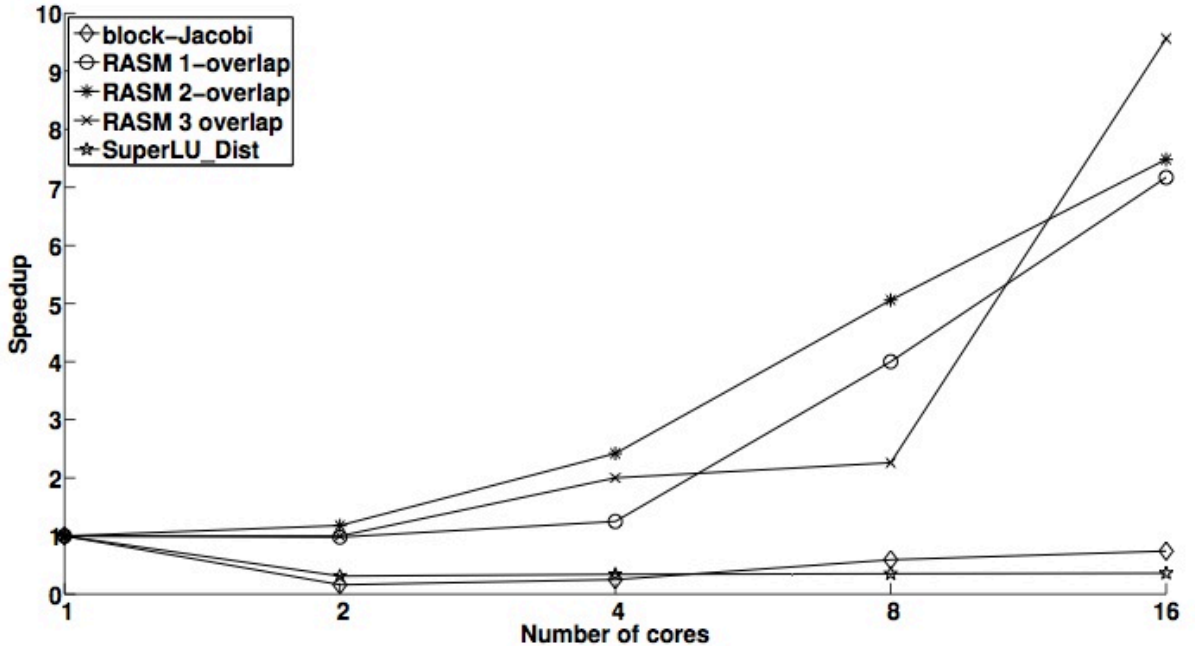
Two processors



Achieving Real-Time Dynamic Simulation Speed: 2. Efficient parallel linear solvers



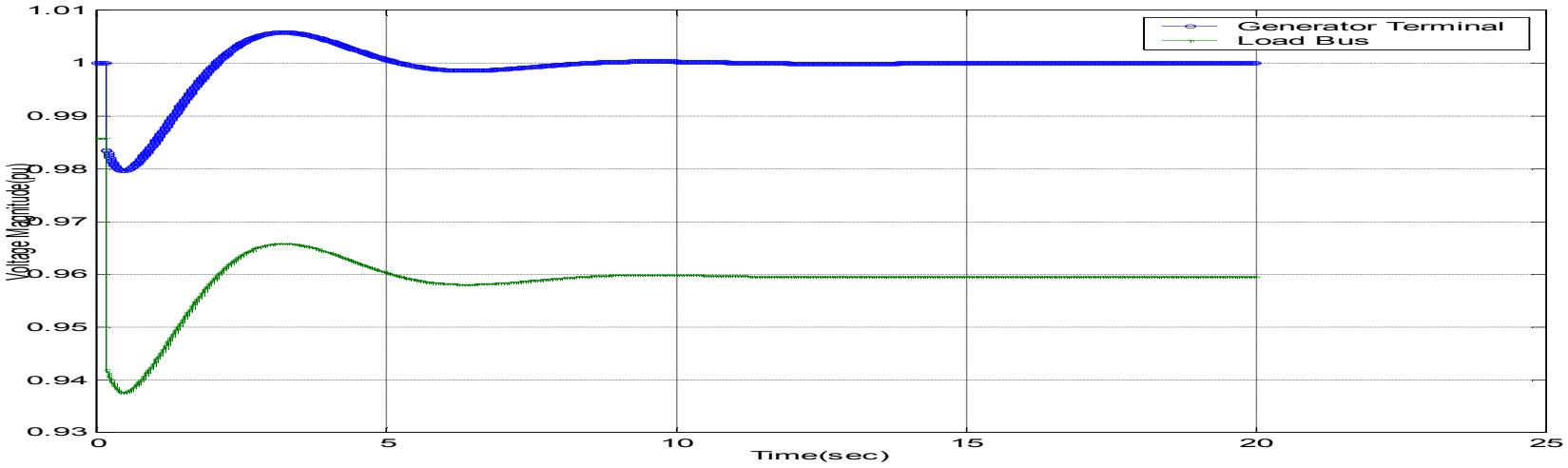
Linear solver is the biggest computational bottleneck!!

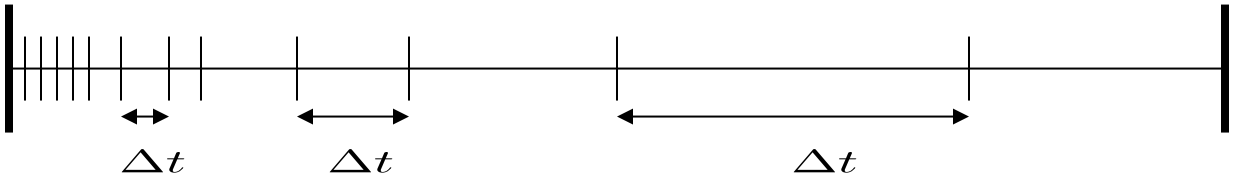


Parallel linear solver achieved 10X linear solver speedup on 16 cores for a 50,000 bus test system

Achieving Real-Time Dynamic Simulation Speed: 3. Adaptive Time-stepping

Take smaller steps when things are evolving rapidly, larger steps otherwise

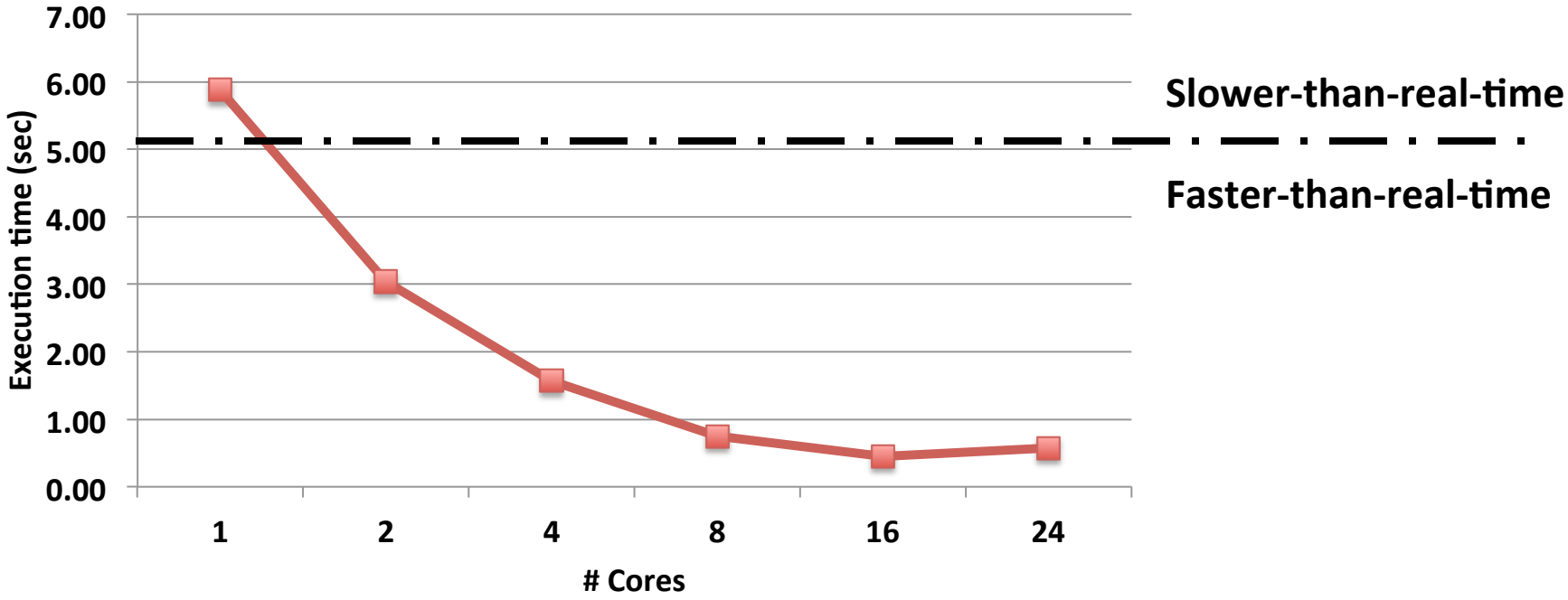




Time-step adaptivity

$$\Delta t_{n+1} = \Delta t_n \left|\left| e_{n+1} \right|\right|^{-1/p}$$

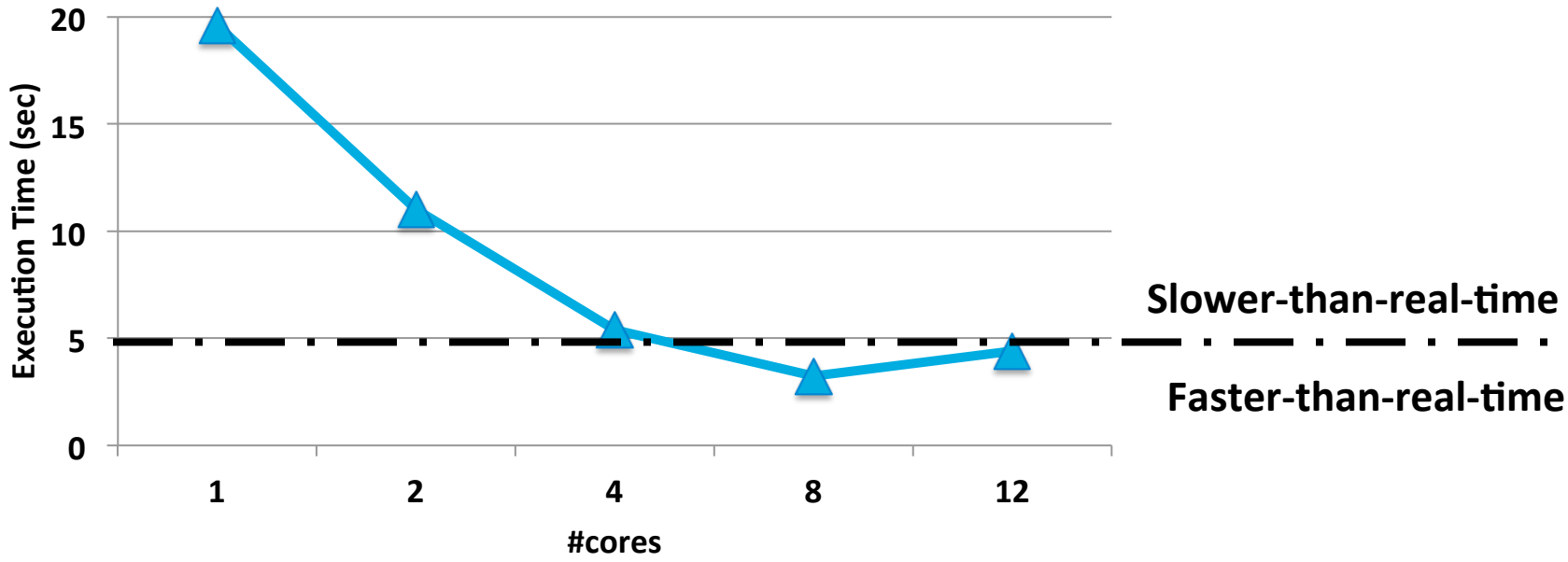
Achieving Real-Time Dynamic Simulation Speed: Putting it all together: Test case 1



Scalability plot of a 5 second simulation of a 20,000 node system

- Achieved faster-than-real-time speed of under 1 second execution time on 16 cores.
- Execution time using state-of-the-art algorithm on single core = 35 seconds

Achieving Real-Time Dynamic Simulation Speed: Putting it all together: Test case 2

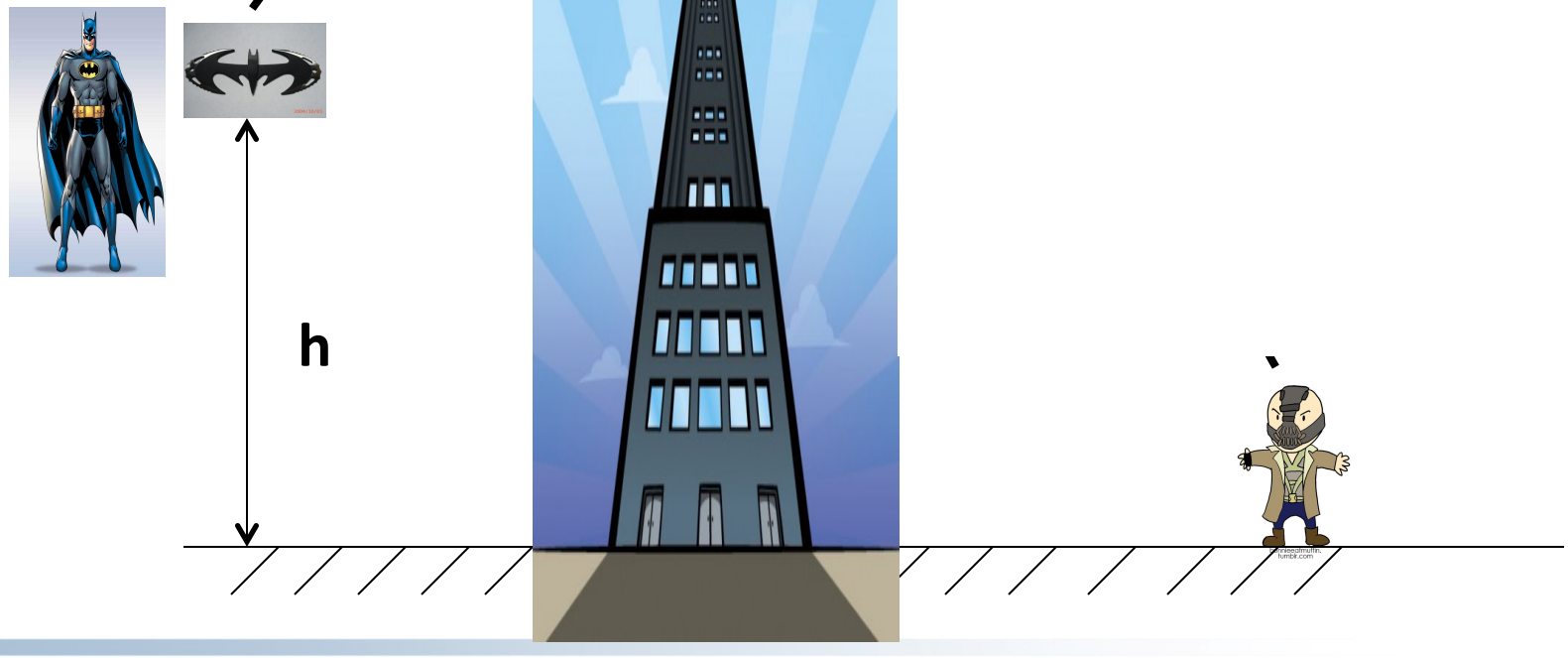


Scalability plot of a 5 second simulation of a 20,000 node system ~ 150,000 variables

- Achieved real-time speed of under 5 seconds execution time on 8 cores.
- Execution time using state-of-the-art algorithm on single core = 300 seconds

Preventative control of Power Blackouts: The Gotham Analogy

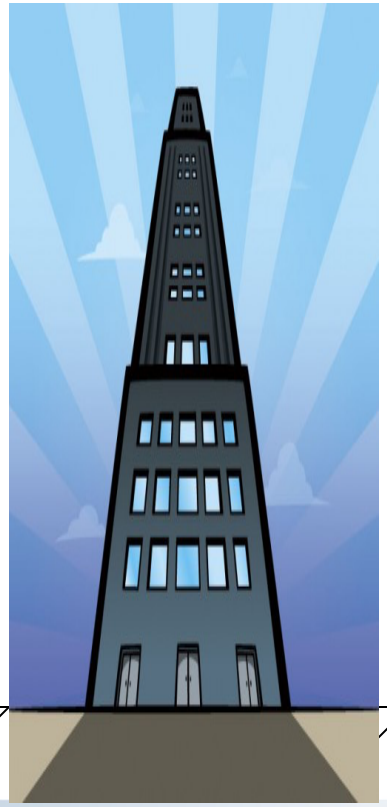
JOKER'S NO FLY ZONE



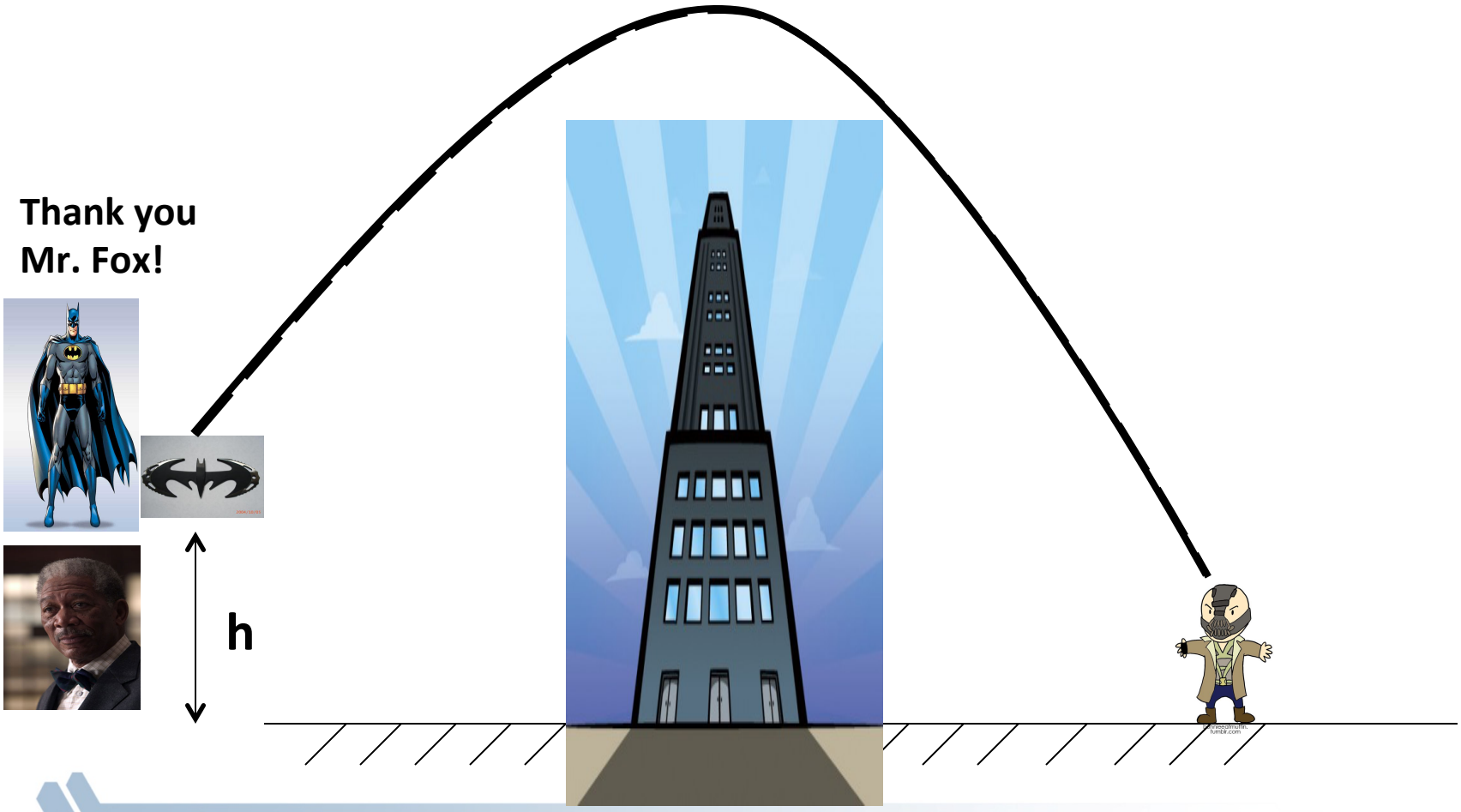
Preventative control of Power Blackouts: The Gotham Analogy

You need to retire Alfred

h

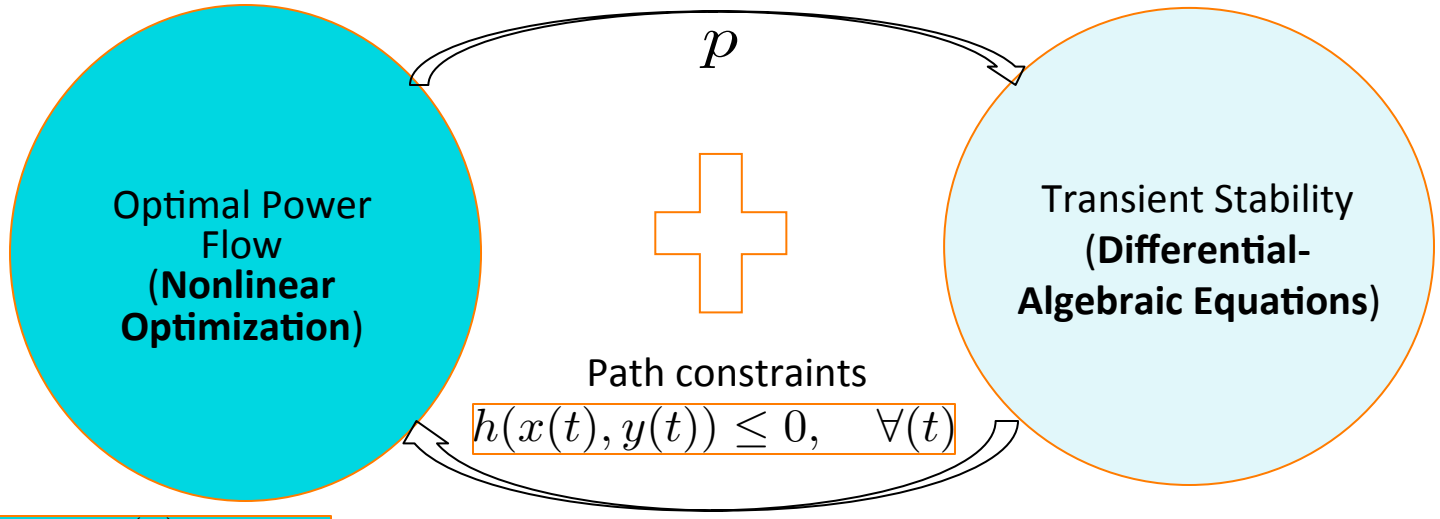


Preventative control of Power Blackouts: The Gotham Analogy



Preventative Control of Power Blackouts

- Modify initial operating point by **including scenarios that could violate security and potentially lead to blackouts.**
- Need to solve an "Optimal Control" problem



$$\begin{aligned} \min \quad & C(p) \\ \text{s.t.} \quad & g_s(p) = 0 \\ & h_s(p) \le h^+ \\ & p^- \le p \le p^+ \end{aligned}$$

Adjoint-sensitivity based gradient calculation

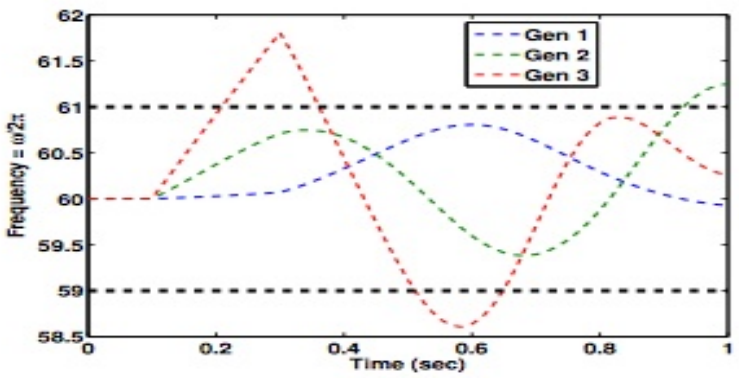
$$\begin{aligned} \dot{\lambda} &= -f_x^T \lambda + g_x^T \mu - h_x \\ 0 &= -f_y^T \lambda + g_y^T \mu - h_y \end{aligned}$$

$$\nabla_p H = \int_0^T f_p^T \lambda \, dt \; - (x_p^T \lambda)\Big|_{t=0}$$

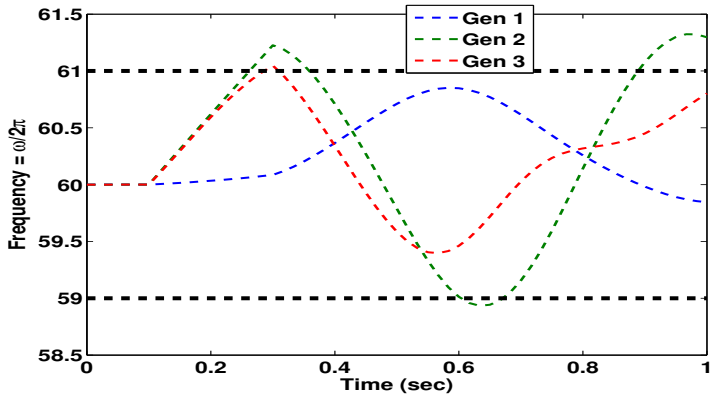
$$\begin{aligned} \dot{x} &= f(x, y, p), \quad x(t_0) = I_{x0}(p) \\ 0 &= g(x, y, p), \quad y(t_0) = I_{y0}(p) \end{aligned}$$

Preventative Control of Blackouts

Without incorporating dynamic scenarios

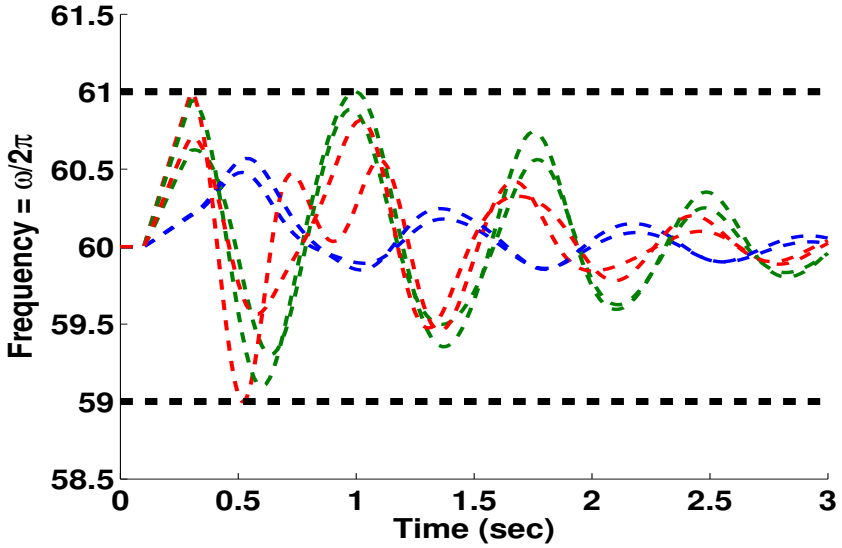


Generator 3 would trip



Generator 2 would trip

Modified dispatch by incorporating both scenarios



Summary

- Presented relevant research on modeling, real-time simulation, and preventive control of large power blackouts.
- We are off to a promising start, but there's still a long way to go.

QUESTIONS??