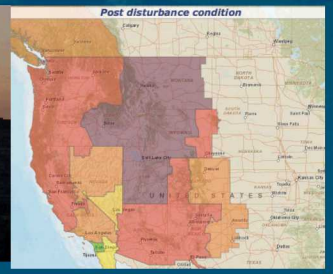
SAND2020-11318C

Approximating Power System Dynamics for Black Start Planning



THE 4TH IEEE SYSTEMS MODELLING CONFERENCE: A VIRTUAL CONFERENCE
27th October 2020

Walt Beyeler, Kevin Stamber ,Bryan Arguello, Richard Garrett

Sandia National Laboratories

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

Modeling to Support Black-start Planning

Large-scale disruptions are rare, singular events

Specific scenarios can be modeled in detail, however

- The space of possible disrupted conditions can only be sparsely sampled
- Restoration trajectory may be shaped by contingencies, making projections irreducibly inaccurate

Is there a role for a simplified system-level model that might rapidly explore the space of possibilities?

Such an approach has been useful in bounding system response to large-scale disruption to fuel networks.

- Is the model as formulated useful as a surrogate for important power system dynamics?
- What would make it so?

Overview

System-level model for fuel transportation networks

- Purpose
- Formulation

Correspondence to power systems

Closing gaps

Netflow Dynamics (NFD) History and Motivation

NFD Originated as NISAC National Transportation Fuel Model

Developed to give analysts the capability to:

- Integrate data from multiple sources to create an internally-consistent and balanced system representation
- Simulate operation of the infrastructure under a wide range of disruption scenarios

Designed to answer questions of the form:

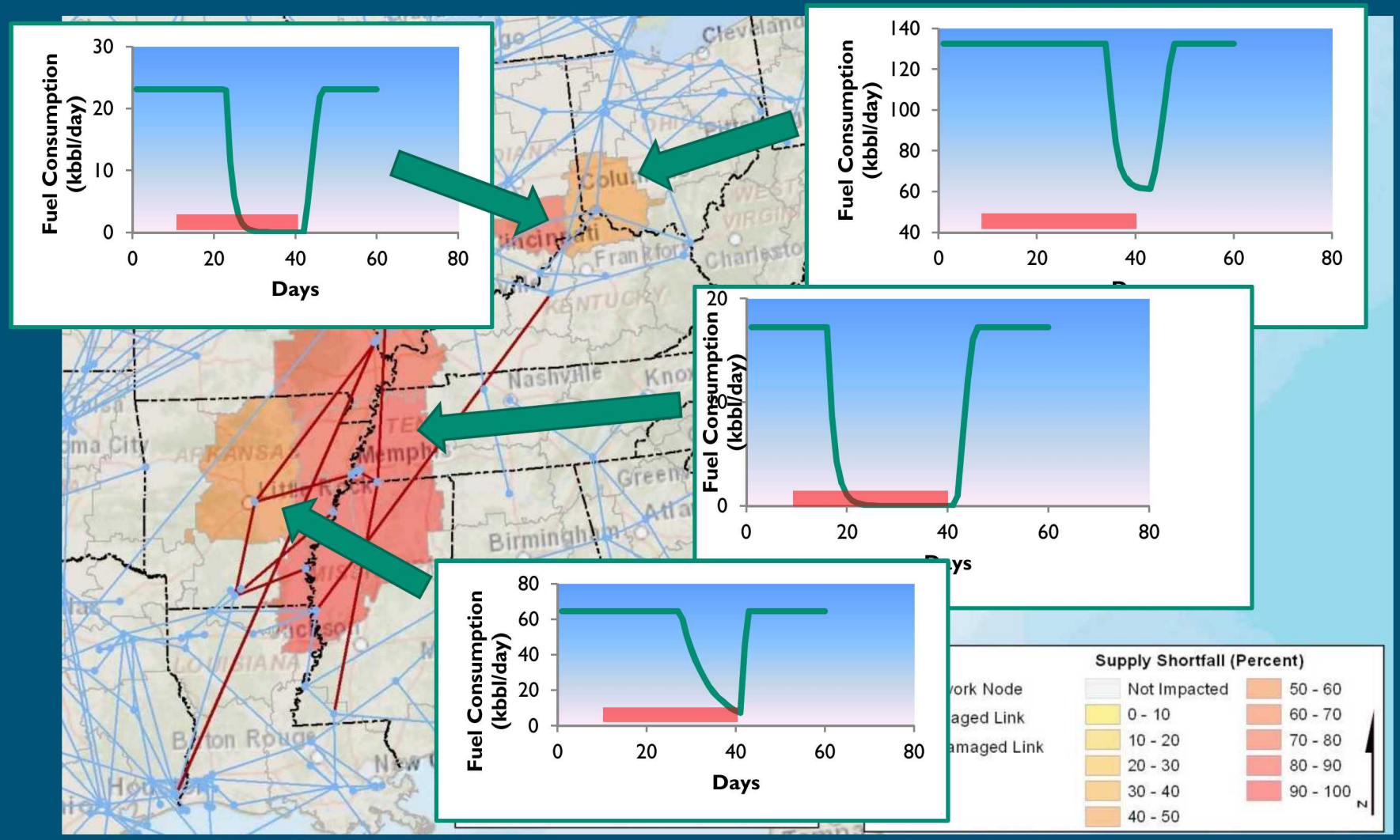
- Which regions would experience shortages of fuel after a specified disruption to one or more components of the fuel infrastructure?
- What would be the duration and magnitude of the shortages

Successfully applied by programs within DHS, DOD, and DOE

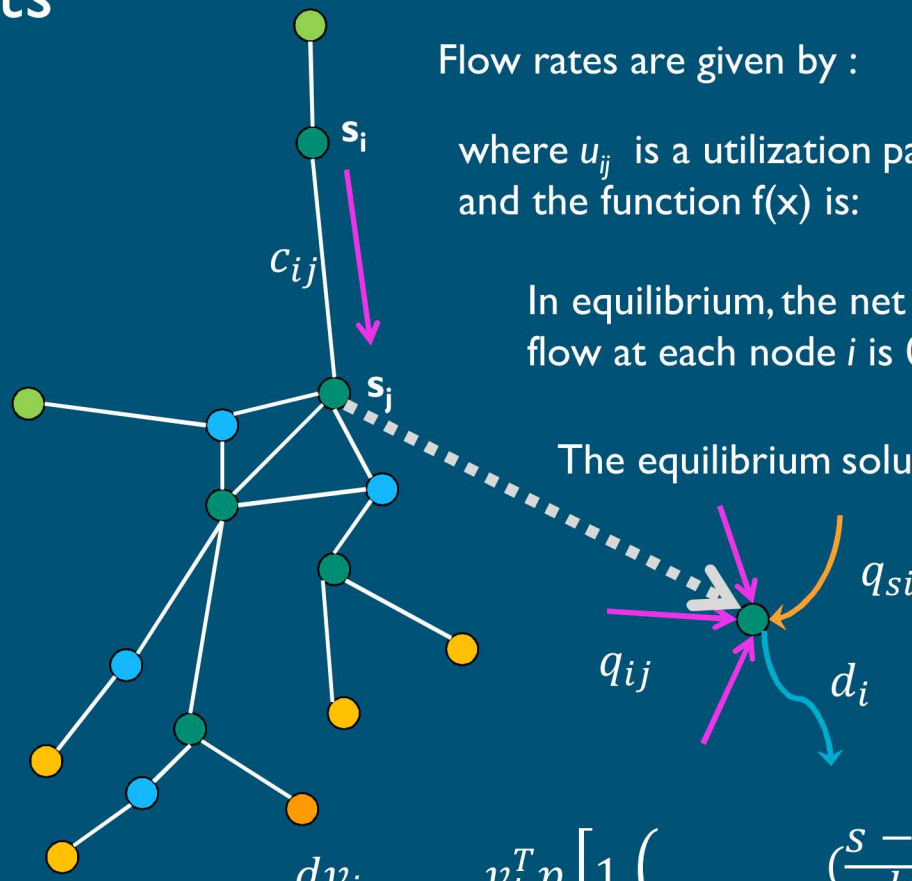
Structure and storage determine shortfall timing and magnitude – US fuel infrastructure

Example application – how a New Madrid earthquake might affect availability of motor fuels

Intensity and timing of responses depends on network structure as well as operator responses



Satisfy demand subject to mass balance and capacity constraints



Flow rates are given by : $q_{ij} = c_{ij}\, f\big((s_i - s_j)u_{ij}\big)$ (1)

where u_{ij} is a utilization parameter and the function f(x) is: $f(x) \equiv 1 - e^{-x}$ (2)

In equilibrium, the net flow at each node *i* is 0: $\sum_j q_{ji} + q_{si} - d_i = 0 \quad \forall i$ (3)

The equilibrium solution $\{\hat{s}_i\}$ is obtained by solving equations (1-3)

In the transient case, net inflow into a node results in the accumulation of stored fluid:

$$\sum_j q_{ji} + q_{si} - d_i = \frac{dv_i}{dt} == \frac{v_i^T p}{2b}\left[\frac{1}{2}\left\{1 + \frac{(\frac{s-a}{b})}{\left[1 + (\frac{s-a}{b})^2\right]^{\frac{1}{2}}}\right\}\right]^{p-1}\left[1 + (\frac{s-a}{b})^2\right]^{-3/2}\frac{ds_i}{dt} \quad \forall i$$

where *p*, *a* and *b* are storage parameters

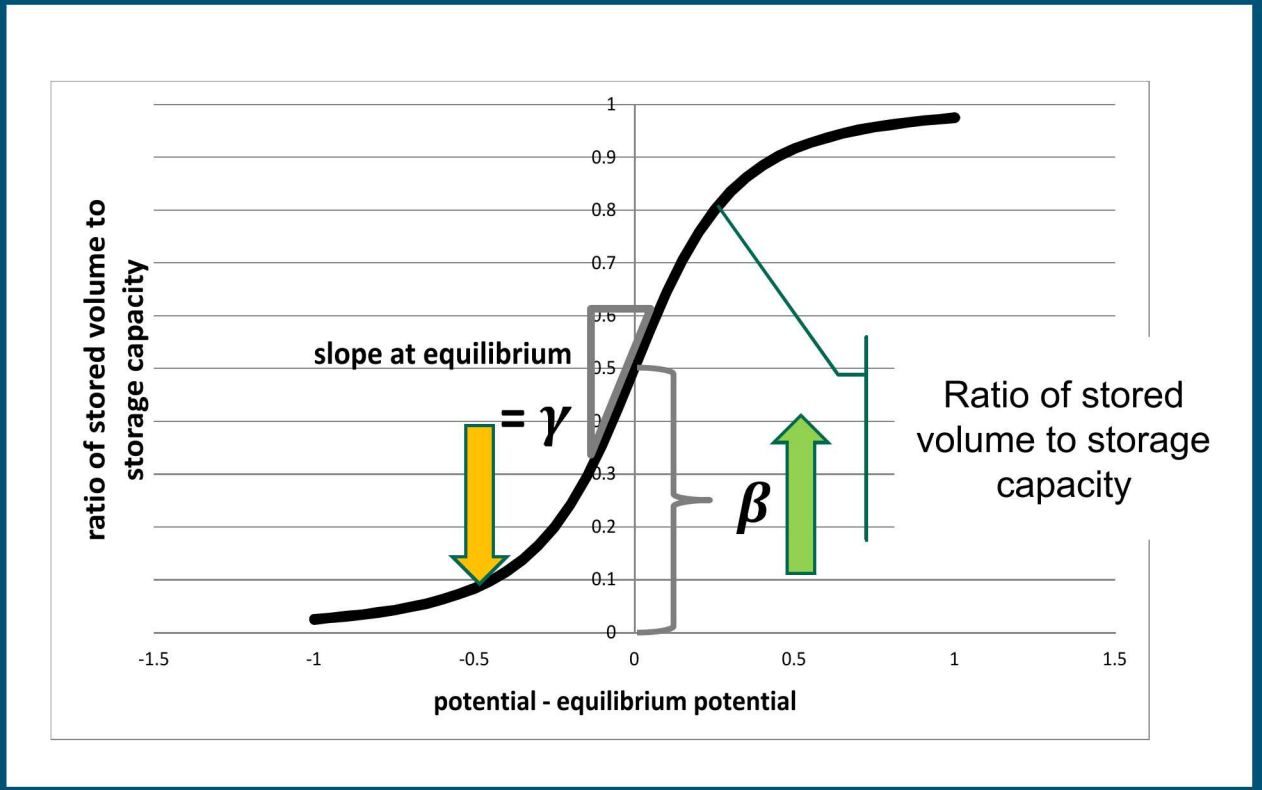
Corbet et al., Reliability Engineering and System Safety 169 (2018) 451–465

Nodal storage dynamics

Fluid volume at nodes is the key dynamical variable

Flow imbalances at nodes lead to accumulation or dissipation of fluid. Physical constraints on upper and lower endpoints are modeled using a sigmoid function connecting potential and stored volume

Following disruption, fluid networks can reach a new equilibrium with a persistent net change in fluid levels

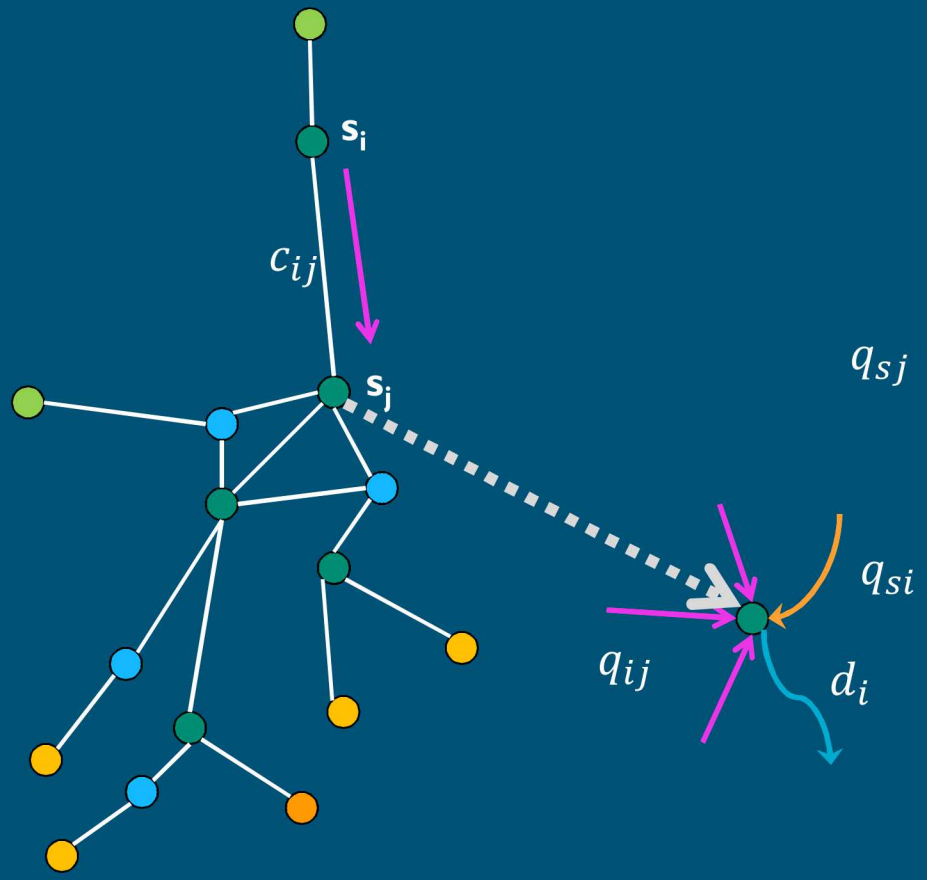


Generator rotational energy is an analog in power systems

Net power imbalances drain energy at a rate that depends on node characteristics (rotor inertia vs. storage volume)

Rotor energy *must* be restored to retain system function

Incorporating control dynamics at generator nodes



q_{sj} must adapt to potential at the node so that potential is retored to its equilibrium level a

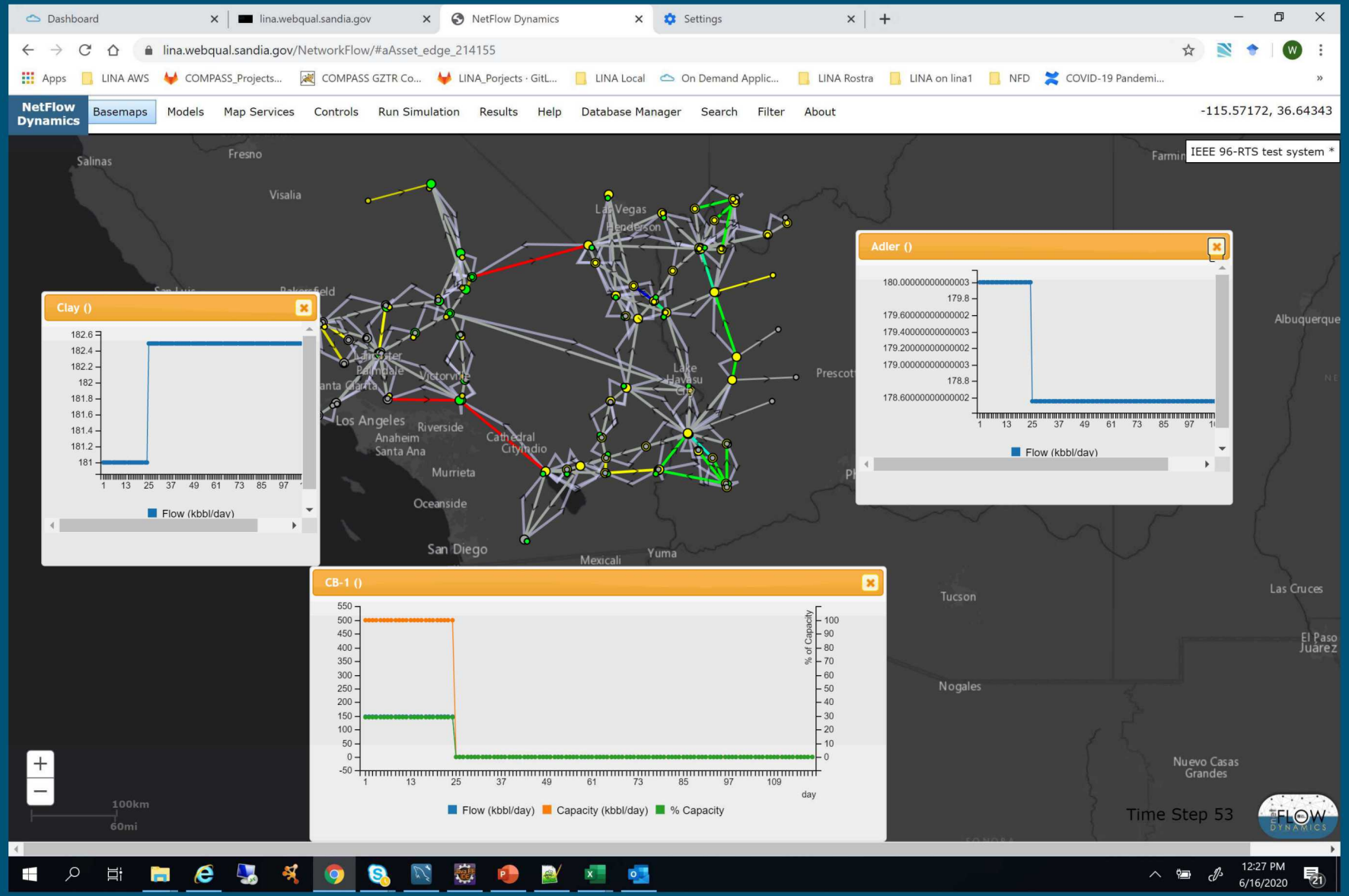
$$q_{sj} = c_{si}\, f\big((s_s - s_i)u_{sj}\big)$$

Defining a goal-seeking dynamic for the utilization parameter u_{sj} preserves the upper limit on rate c_{si}

$$\frac{du_{si}}{dt} = u_{si} - \left(\frac{s - a}{t_s}\right)$$

IEEE RTS 96

We're using the RTS 96 network as a test case…



Status and Directions

With a simple elaboration of its governing equations, NFD may be able to represent some aspects of overall system dynamics relevant for evaluating possible restoration trajectories. We are current investigating its value as a complementary system-level model.

Evaluation on a simple test system will help assess performance characteristics vis-à-vis existing dynamical simulations