Electric Grid Operations Visual Storytelling: Past, Present, and Future

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TEXAS A&M UNIVERSITY

Acknowledgments

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- Slides also include contributions from many of my students, postdocs, staff and colleagues at both TAMU and UIUC
- The views presented here are my own, and are partially contained in a recently accepted paper at the 2022 Kansas Power and Energy Conference

TAMU Electric Grid Research Day: April 22

- On Friday April 22, 2022 the Smart Grid Center and the TAMU Energy and Power Group will be hosting Research Day
  - The event is free and runs from 9 am (with breakfast at 8:30 am) through 4pm, with lunch included
  - Location is the A&M Center for Infrastructure Renewal
- Required Registration is at smartgridcenter.tamu.edu/
  - This link also includes a tentative agenda
  - In addition to research presentations there will be hands-on activities

Our Energy Future Could be Quite Bright!

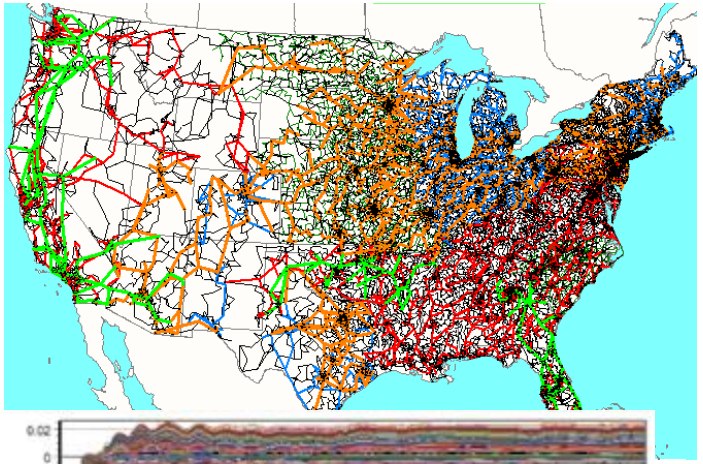
- My professional goal is to help in the development of a sustainable and resilient electric infrastructure for the entire world.
- Electric grids are in a time of rapid transition, with lots of positive developments.
- I think our electric energy future could be quite bright! But there are lots of challenges with this transition, and this requires better techniques for understanding the operation of electric grids (past, present, and especially for the future). This is the focus of the presentation

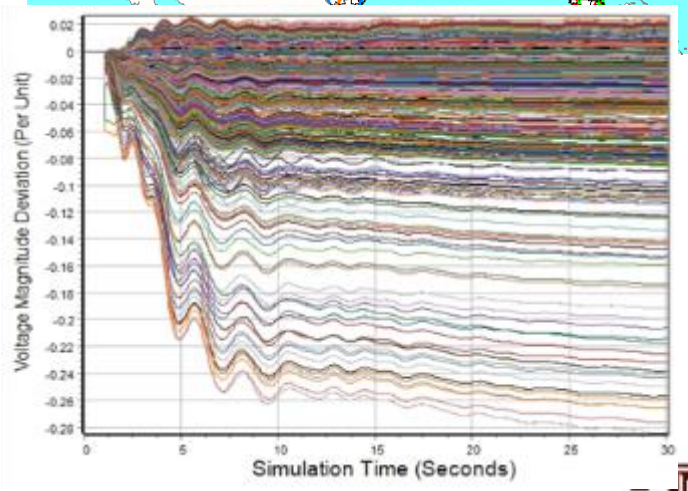
Overview

- Presentation focuses on how better electric grid operations storytelling can help us achieve this desired future
- First a caution! If you are looking for a webinar with lots of math equations you might want to stop watching right now; there are no explicit equations here
- The presentation does contain a large amount of solid engineering, but integrates that in with references to art, history and hopefully at least some storytelling

Electric Grids Create Lots of Data You Could Say There Is Big Data Problem

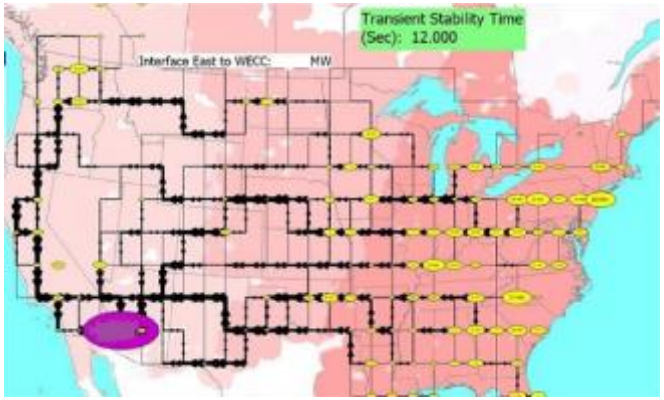
- Power system operations and planning are a rich source of data
  - SCADA has traditionally provided a grid data at scan rates of several seconds
  - Thousands of PMUs are now deployed providing data at 30 times per second
  - In planning many thousand of studies are now routinely run, with a single stability run creating gigabytes





An Example: East-West Dynamics Study

- One project in 2020 looked at the dynamic aspects of an ac interconnection of the Eastern Interconnect and the WECC
  - We did lots of dynamic simulations some going out for minutes
  - The Model has 110,000 buses, 244 different types of dynamic models, 48,000 model instances



- No major showstoppers with this interconnection
- A human factors challenge was to know what happened in a simulation, and then to explain the results to a variety of different audiences

Motivation for The Electric Grid Storytelling Approach

- A key motivation for the work presented here came from the first two lines in [1],

  "Over the decades of the development of visual analytics techniques, researchers created sophisticated visual analytics tools for analysts to explore complex problems involving large amounts of data. However, when such tools and findings are demonstrated to those who lack visual analytics knowledge and skills, it is not unusual to get feedback such as "fancy visuals, cool interactions, but what does this mean?"

- This led us into the literature looking at taking big data and using it to develop an integrated and seamless story

[1] S. Chen, et. al., "Supporting Story Synthesis: Bridging the Gap between Visual Analytics and Storytelling", IEEE Trans. on Visualization and Computer Graphics, Vol. 26, July 2020, pp. 2499- 2516

Presentation in a Nutshell

- The goal of the presentation is to show how storytelling techniques can be used to make sense of electric grid operations: past, present and especially with the future
- The main focus is on techniques for eventually mostly auto-creating short (on the order of a few minutes) videos that tell an electric grid operations story
  - The videos may have audio narration, though the ones presented here do not
- Before getting into the details, some background is helpful

Big Data is Nothing New

- Essentially every day any person with normal senses takes in a vast amount of data
  - Some we'll remember throughout our lives, but most is quickly forgotten
- Any collective human experience generates lots of data, with again most quickly forgotten, but still a lot is retained if nothing else in our memories
- People have been storing data for many years, with the Library of Alexandria containing perhaps a half a million scrolls before it burned in 48 AD
- Historically most data wasn't explicitly stored, again except in the memories of the participants

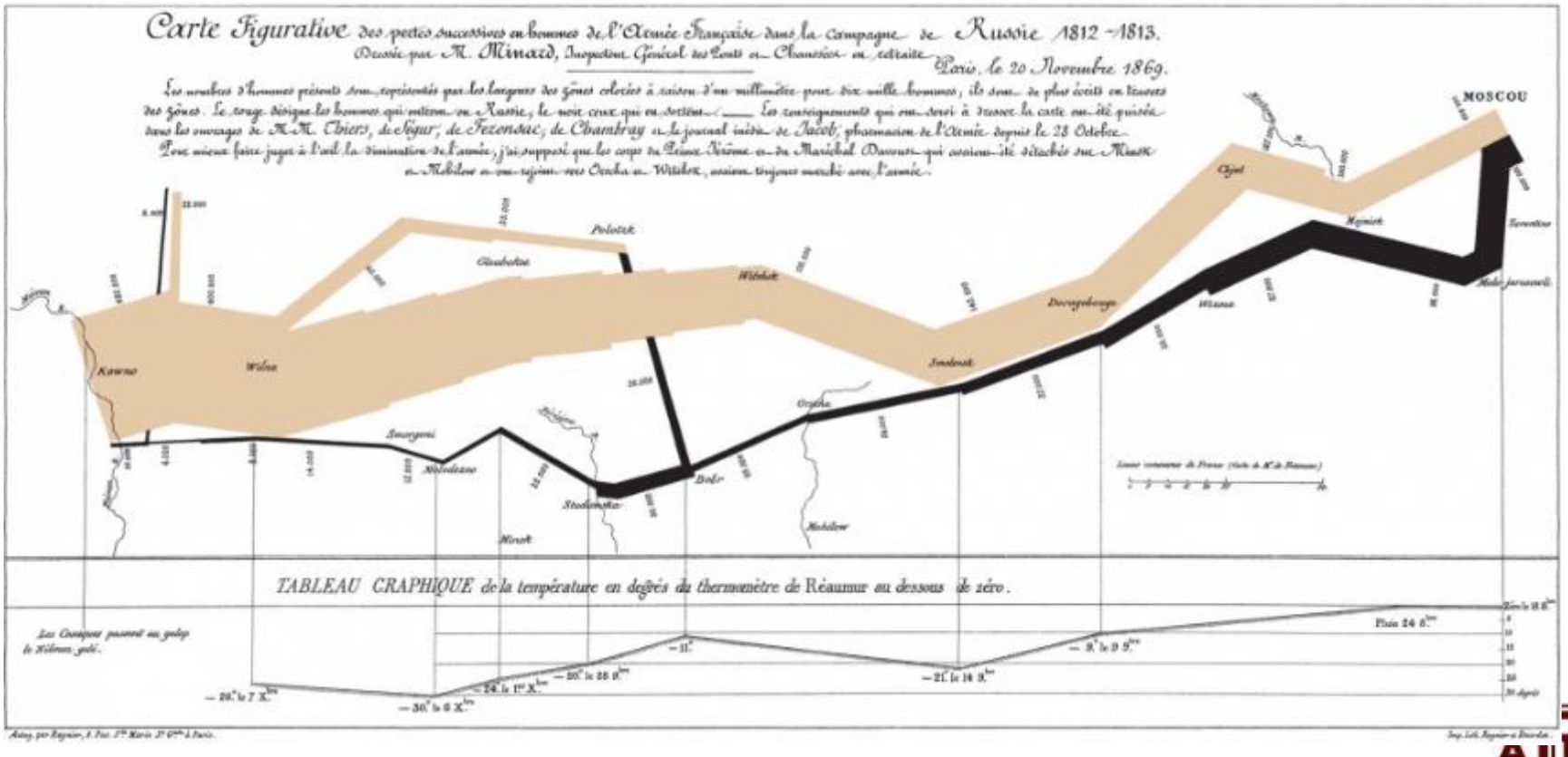
Making Sense of Our History

- The challenge has been how to make sense of this collection of data, and pass it on to others
- Common means of synthesizing and communicating have included books, drawings, paintings, illustrations, songs
  - More recently recordings, movies, computer programs, computer animations
- Throughout we have primarily used stories, with much of this storytelling oral, but some written, some in paintings, and more recently in movies and computer animations

“The Voyage of Life” by Thomas Cole, 1842
Does this relate to the electric grid?

Books by Tufte are a Good Source for Historical Images for Data Visualization

Illustration by Charles Minard from 1869 on Napoleon's march to, and retreat from Moscow in 1812; Called the "Best Statistical Graphic Ever Drawn"



422,000 troops enter Russia in June 1812; 10,000 are left in Dec. 1812

Stories and Storytelling

- A story is defined by Merriam-Webster as, “an account of incidents or events”
  - Stories can be historical or fictional, and told for entertainment, education, or to convey moral or spiritual lessons (a parable; “There was a man who had two sons..”)
- While storytelling often invokes its common meaning of orally telling a story, more broadly its definition includes a variety of ways of presentations including the video animation approach given here
- The focus of the slides is how to use storytelling techniques to convey information about electric grid operations

Source: E. Tufte, The Visual Display of Quantitative Information, Graphics Press, Cheshire, CT, 1983.

Another Motivation for this Presentation

- In 2020-2021 Anjan Bose and I wrote a white paper for DOE titled, “Electricity Transmission System Research and Development: Grid Operations” [1]
- For paper I did quite a literature search on grid operations and found that over the last several decades there are many papers on new algorithms, mostly applied to small grids, but very little about how the grid is actually operated or even on how existing algorithms are applied to grid operations
- The story of electric grid operations isn’t being told in most of the archival literature

[1] www.energy.gov/sites/default/files/202105/Grid%20Operations%20Bose%20Overbye_0.pdf

Type of Electric Grid Stories We Could Tell

- Telling the full story of the grid is too big to completely present
  - A good book on the North American grid is *The Grid* by Julie Cohn (MIT Press, 2017)
  - The first chapters in *Analytic Research Foundations for the Next-Generation Electric Grid* (National Academies Press, 2016; www.nap.edu/21919) provide some background
- A focus could be on a portion of the grid for a short time
  - August 14, 2003 Blackout
- Or over larger time periods for a few components
- Or a combination
  - J. Cohn, “When the Grid Was the Grid: The History of North America’s Brief Coast-to-Coast Interconnected Machine,” *IEEE Proceedings*, January 2019

Example Short Stories to Tell: **Past**, **Present**

- For a particular utility or ISO, short (a few minutes each) videos on the top 20 most interesting operations scenarios (**past**)
  - Audience: new engineers and other employees
- The operational history of a device (e.g., braking resistor, key transmission line, series capacitor) (**past**)
  - Audience: engineers, researchers
- A summary of what happened in an electric grid over the last day, week or shift (**present**)
  - Audience: Executives, operators, engineers
- Setting up an interactive simulation
  - Audience: Broad, with students one demographic

Example Short Stories to Tell: **Future**

- Most engineering is forward looking: we learn from the past to help provide a better future
- Application of historical weather or other high impact events to the grid of today (**future**)
  - Audience: Broad including engineers, researchers, students (e.g., during Feb 2021 College Station got down to 5° F, whereas in Jan 1949 it got down to -3° F)
- Normal and abnormal days in the life of the grid in 2040 (**future**)
  - Audience: Broad including policymakers
- Developing and showing predictions of the future makes for challenging storytelling

A Computer Animation Telling the Story of the US Civil War in Four Minutes

- Nothing can fully tell the full story of the US Civil War, but there is a computer animation at the Abraham Lincoln Museum (Springfield, IL) that tells quite a bit of the story in four minutes

The Basics of Storytelling

- More papers on storytelling associated with scientific and information visualization have appear recently with [1] providing a good survey
- People tend to like stories, but it helps to know what point you would like to convey! What is the purpose?
- How much time is available to tell the story?
- With technical storytelling you need to know your audience; e.g., what electric grid familiarity?
- Basics of a story are pretty common: setup and characters, tension, action, climax, resolution
  - Tension and action can rise and fall a number of times

[1] C. Tong, et. al., "Storytelling and Visualization: An Extended Survey," *Information*, 2019, vol. 9, http://dx.doi.org/10.3390/info9030065

A Great Example: The 8/14/03 Blackout Report

- The 8/14/03 Blackout Report does a great job of telling the story of the event
  - Chapters 1 to 4 are the setup and characters, Chapters 5 tension rising and action, Chapter 6 climax, Chapters 7, 10 resolution (Chapters 8 and 9 are on nuclear and cyber)
- At 200 plus pages it is akin to a feature length file (and deservedly so)
- How could it be told in an hour long presentation or in a few minute video?

The report is available at www.energy.gov/sites/default/files/oeprod/DocumentsandMedia/BlackoutFinal-Web.pdf

A Quite Short Story I Like to Share: Grid Frequencies During the 2022 Super Bowl

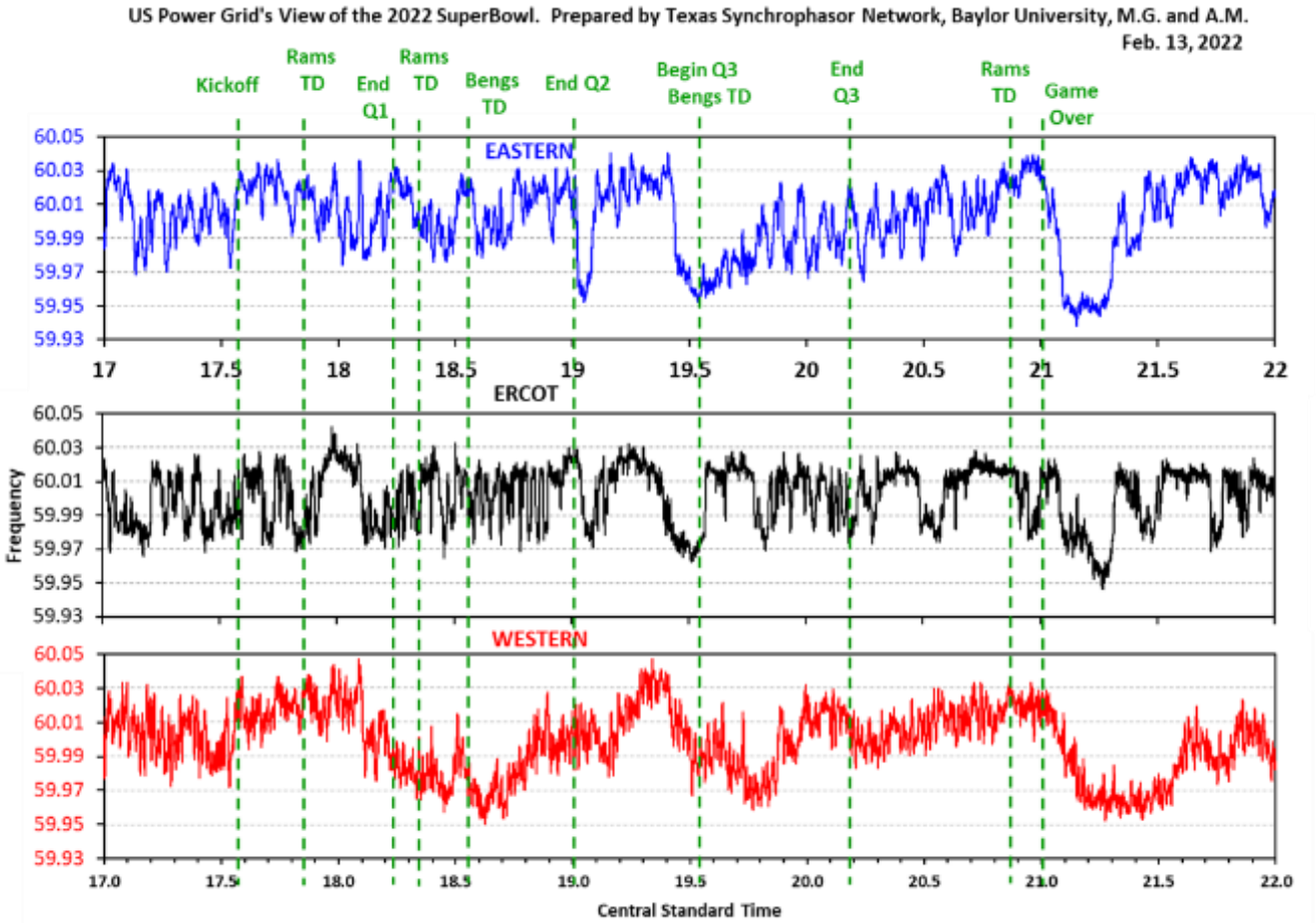


Image provided by Dr. Mack Grady of Baylor University

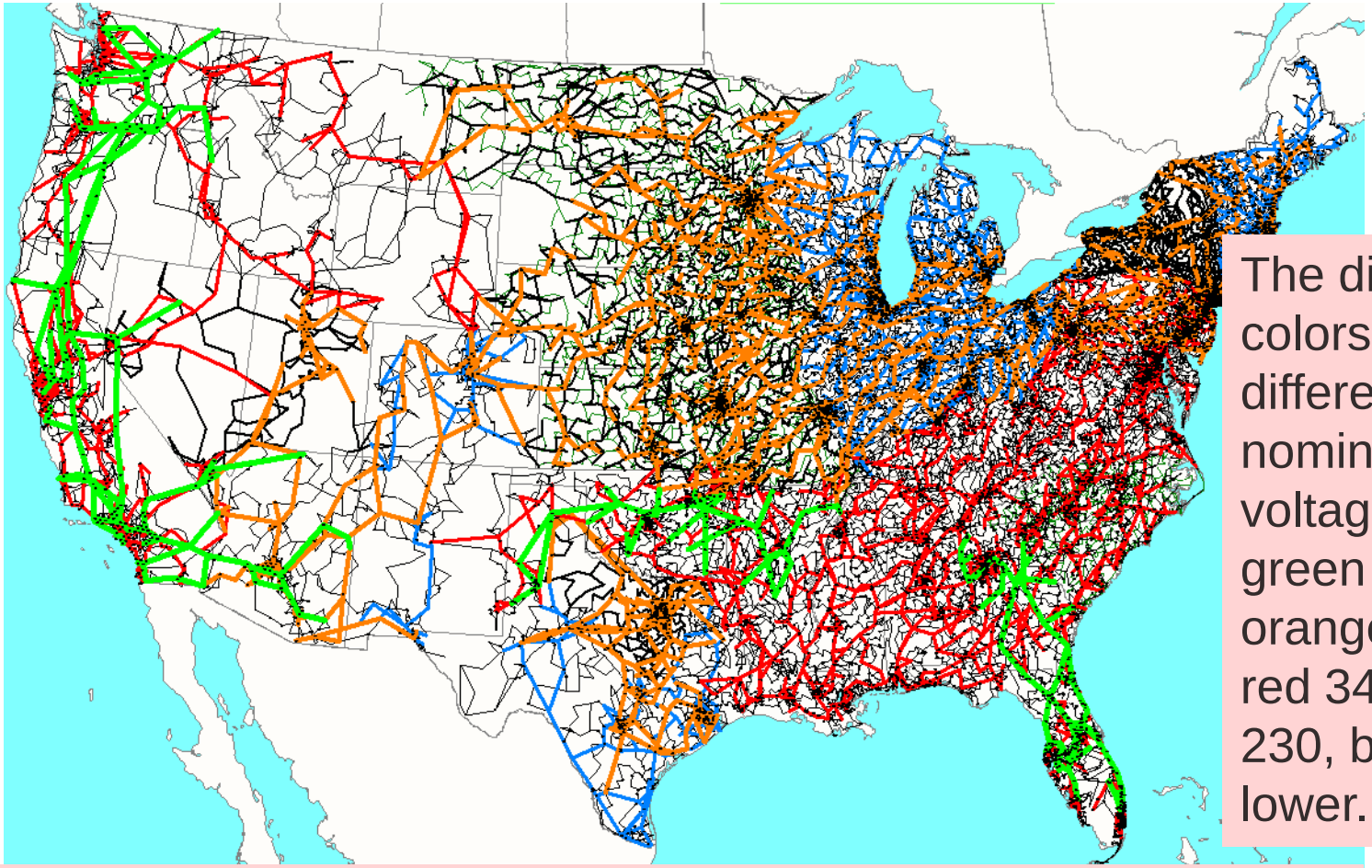
Aside: Real versus Synthetic Grids

- When available I prefer to work with real (actual) grid models and data
- However access to actual power grid models is often restricted (CEII), and this can be a particular concern with storytelling where the focus is on clearly showing aspects of grid strengths and weaknesses
  - Models and data cannot be freely shared with other researchers, and even presenting results can be difficult
- A solution is to create entirely synthetic (fictitious) models the mimic characteristics of actual models
  - Kudos to the US DOE ARPA-E for funding work over the last seven years in this area; “realistic but not real”

Large-Scale Synthetic Grid Models and Results are Now Available

- There are now synthetic grid models that go up to an 82,000-bus one grid modeling the contiguous US (CONUS)
  - Our synthetic grids have embedded geographic coordinates; the TAMU ones are available at **electricgrids.engr.tamu.edu**
- The widespread availability of these grids is greatly helping research!
- There are lots of challenges with synthetic grids with one being that they have no significant operational history and people really don't have an intuitive feel for their operation

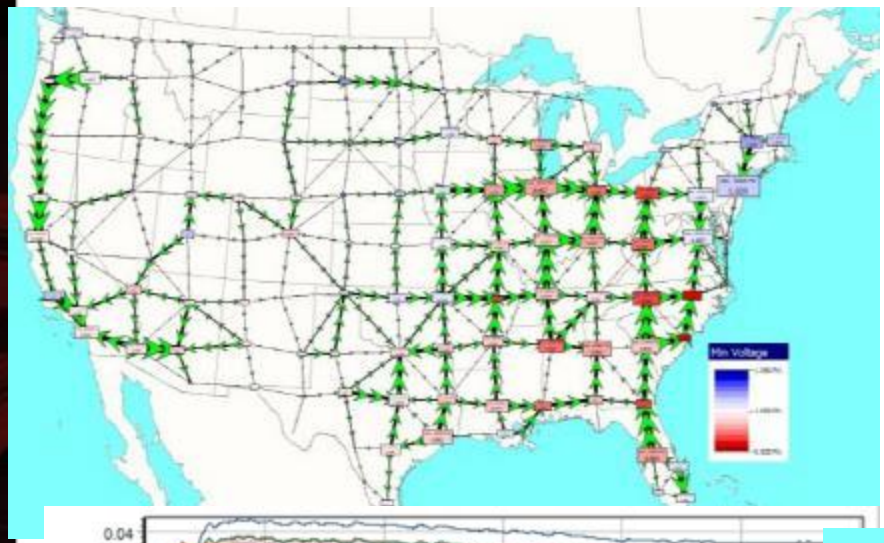
82,000 Bus Synthetic Grid

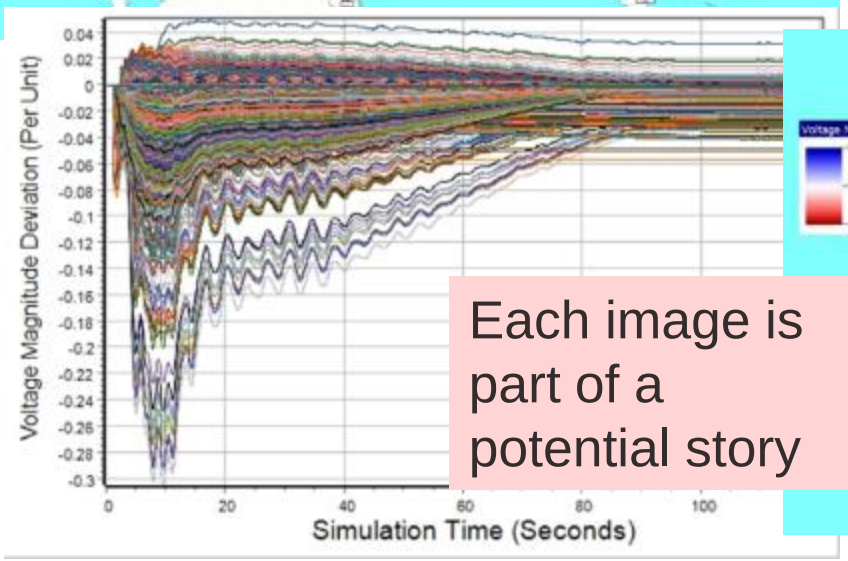


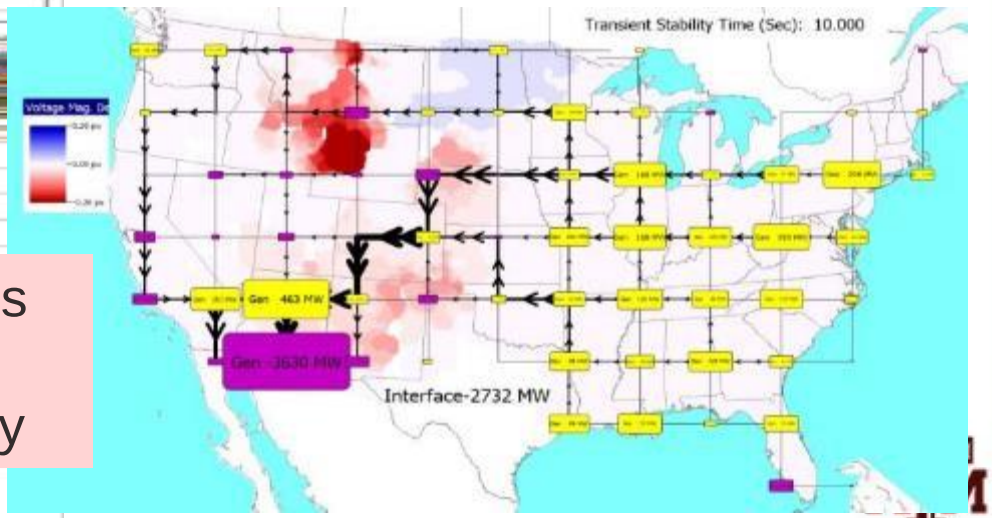
The different colors indicate different nominal kV voltages, with green 765, orange 500, red 345, blue 230, black lower.

This shows the grid, but doesn't tell any story about the grid

Example 82K Visualizations: Elements for Developing Stories



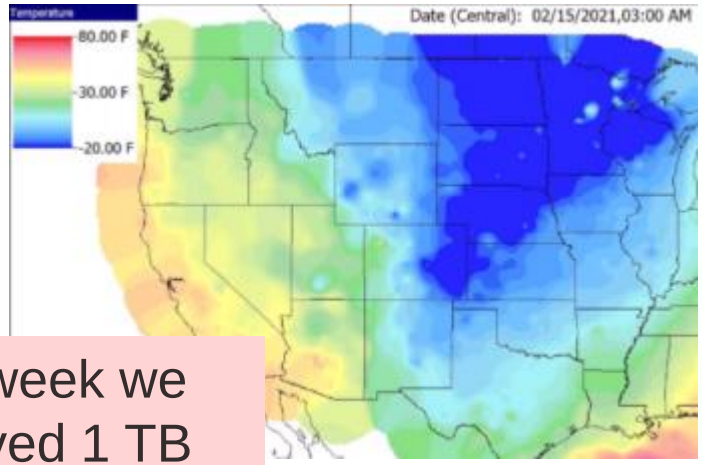




Each image is part of a potential story

Leveraging the Available Data

- What story can be told and to whom depends on the available data
  - For the more distant past there is more limited data
  - For the near past and present lots of data is now available, but there are data access costs and distribution limitations (e.g., CEII concerns)
  - The future can only be simulated, but lots of data can be available; we are now simulating grids (present and future) using historical weather
  - Synthetic grids avoid CEII concerns; but a consistent story needs to be told



This week we received 1 TB of historic weather data

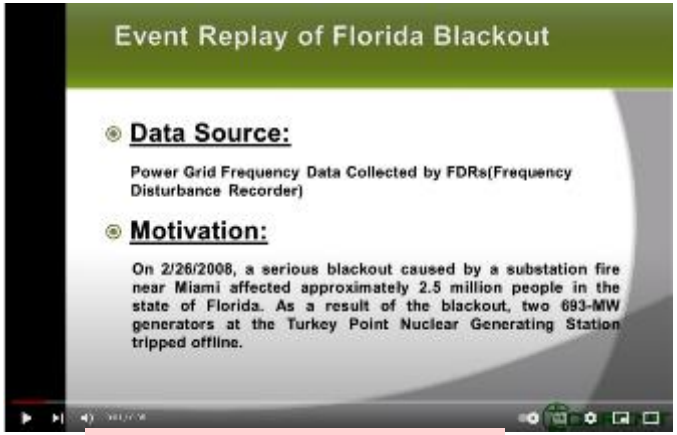
Developing The Story Narrative

- There are a number of ways of developing a story narrative (an ordered sequence of connected events), with [1] providing some good background
- A standard way of developing a video is to use a storyboard, which is a graphic organizer of the different scenes
  - Dates back to Disney in the 1930's
- When applied to data analysis, an approach is to develop "findings" (extracted pieces of information) and to arrange the findings as "story slices" [2]

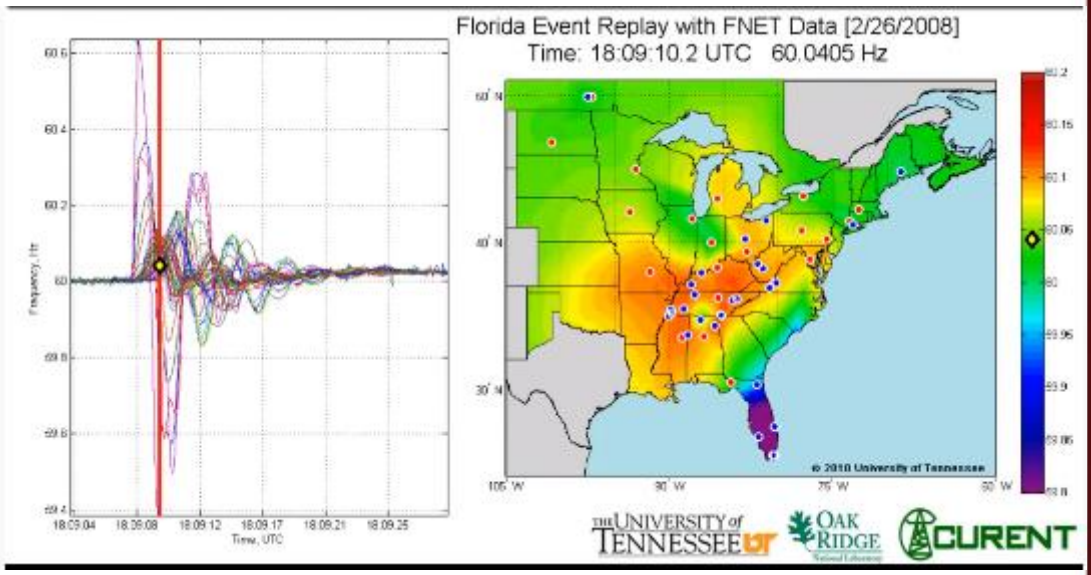
[1] K. Padia, K.H. Bandara, C.G. Healey, "A System for Generating Storyline Visualization using Hierarchical Task Network Planning," *Computers and Graphics*, vol. 78, 2018, pp. 64-75
[2] S. Chen, et. al., "Supporting Story Synthesis: Bridging the Gap between Visual Analytics and Storytelling", *IEEE Trans. on Visualization and Computer Graphics*, Vol. 26, July 2020, pp. 2499- 2516

A Nice Example of a Very Short Story

- A nice example of a 35 second, two slice story is at fnetpublic.utk.edu/
  - YouTube link (the commercial is not part of the story) https://www.youtube.com/watch?v=H7y-oJYpDkM

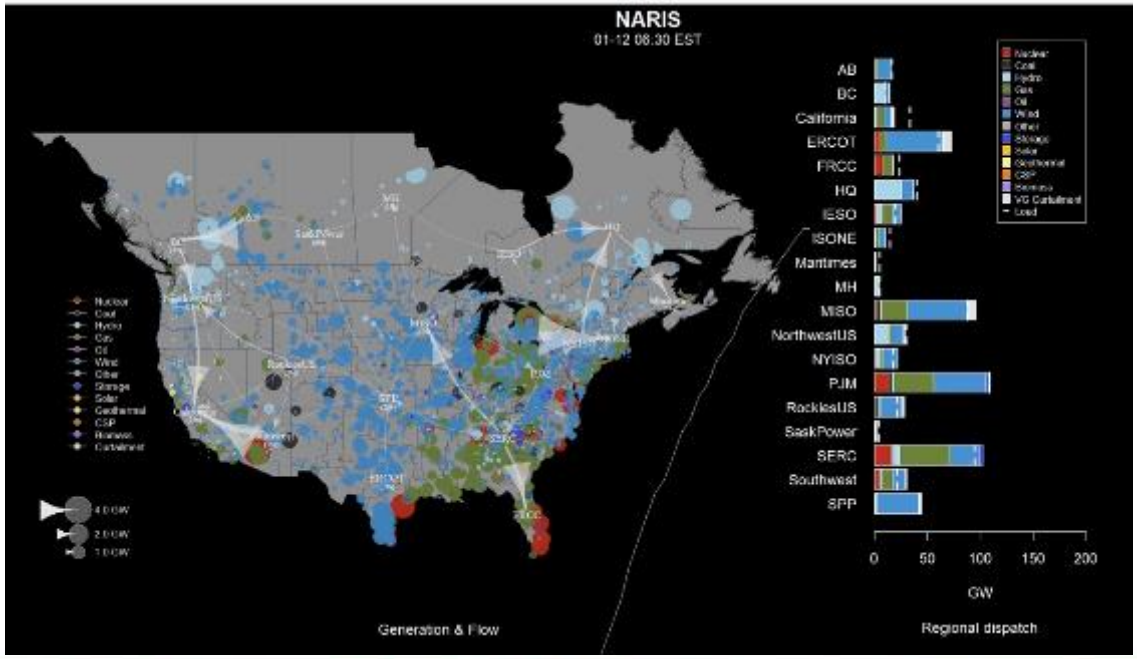


This animation shows several seconds of grid behavior



Another Nice Example

- The National Renewable Energy Lab (NREL) has some nice, short (about one minute each) animation visualizations associated with the North American Renewable Integration Study at
  - www.nrel.gov/analysis/naris.html



This animation shows the operation of a grid over the course of a day

Developing the Story Slices

- Define the question (i.e., the story you want to tell)
  - For example: ISO operational highlights from last week, an interesting event in a utility's history, operational history of an series capacitor
- Gather and clean the data
  - What data is available can limit the question (e.g. PMUs?)
- Use some of the available data analysis techniques to determine the findings
- Determine the best ways to visualize the findings into the story slices

Some Helpful Storytelling Insights

- The story does not need to be told in linear, uniform time; allow the time line to fit the story
  - Set the stage, and then focus on the times with the most action; rewinding time can be used if multiple events are occurring simultaneously, or for showing the consequence of both not doing and doing an action
- The geographic footprint can varying based on the location of the action; zooming and panning can help to provide context

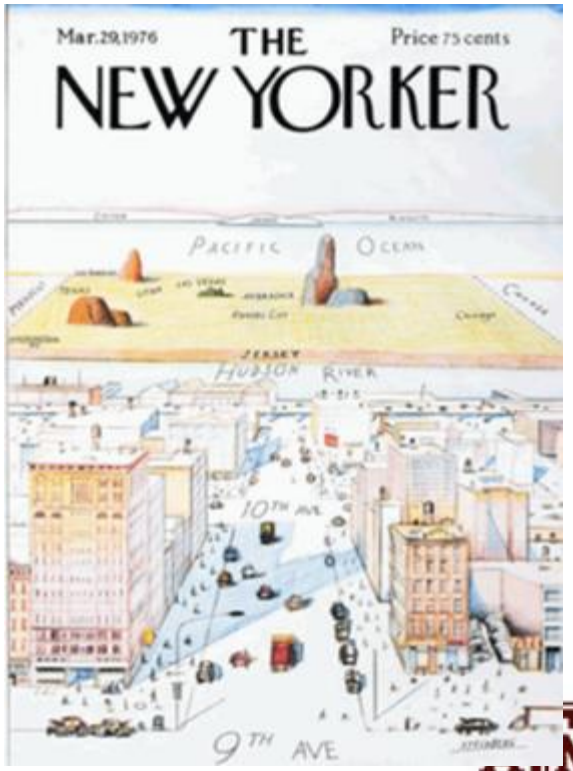


Image source: en.wikipedia.org/wiki/View_of_the_World_from_9th_Avenue

Nonlinear Timeline Examples in the 8/14/03 Blackout Report

Figure 5.1. Timeline: Start of the Blackout in Ohio

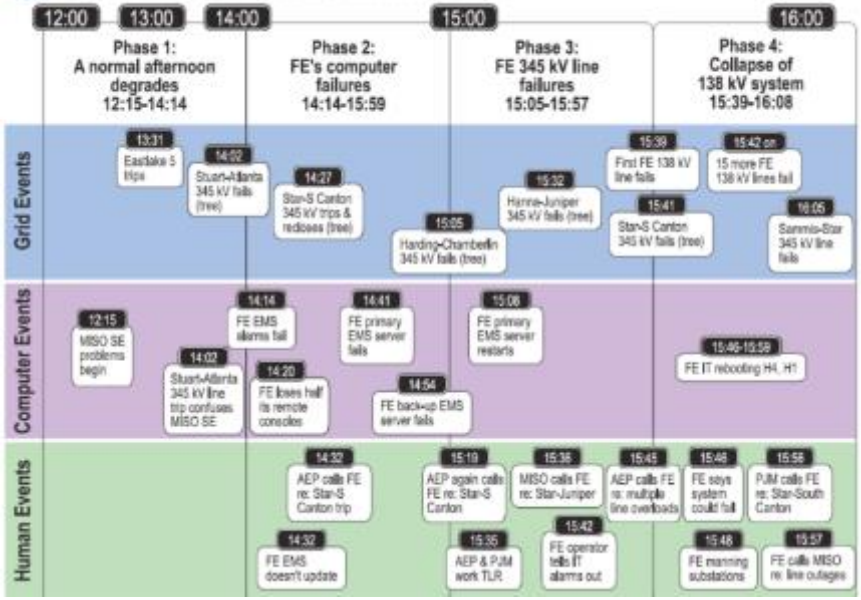


Figure 5.12. Cumulative Effects of Sequential Outages on Remaining 345-kV Lines

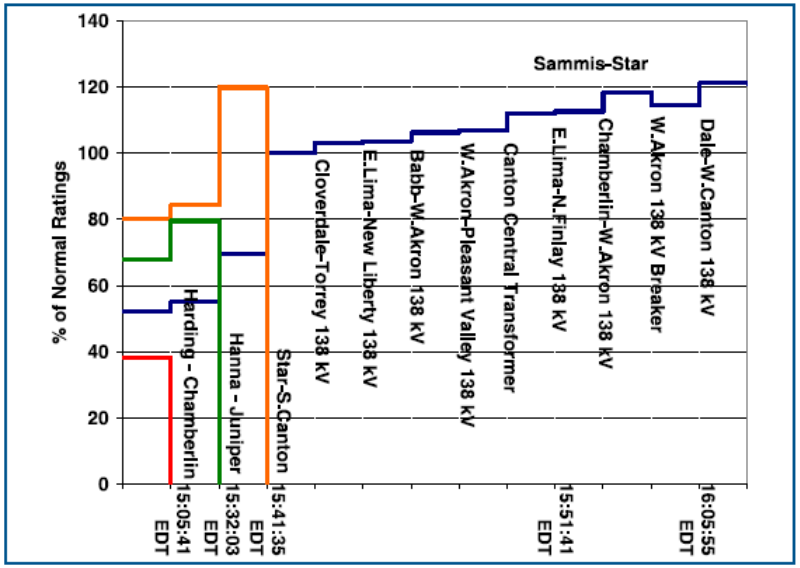


Figure 6.16. Active and Reactive Power and Voltage from Ontario into Detroit

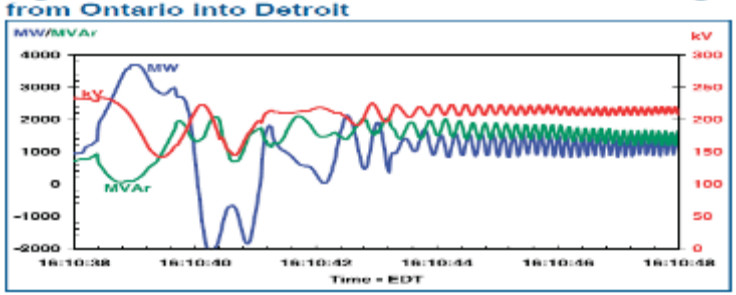


Figure 6.17. Measured Power Flows and Frequency A with Key Events in the Cascade

The report is available at www.energy.gov/sites/default/files/oeprod/DocumentsandMedia/BlackoutFinal-Web.pdf

Different Views in the 8/14/03 Report

Figure 2.7. NERC Reliability Coordinators

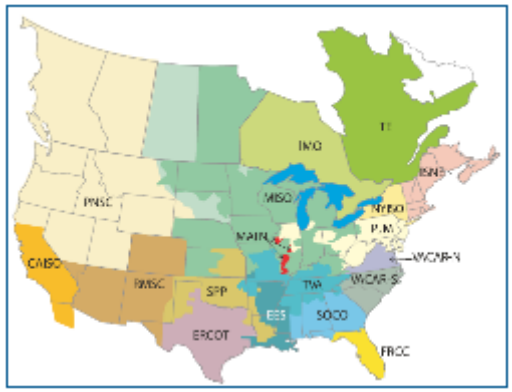


Figure 2.8. Reliability Coordinators and Control Areas in Ohio and Surrounding States

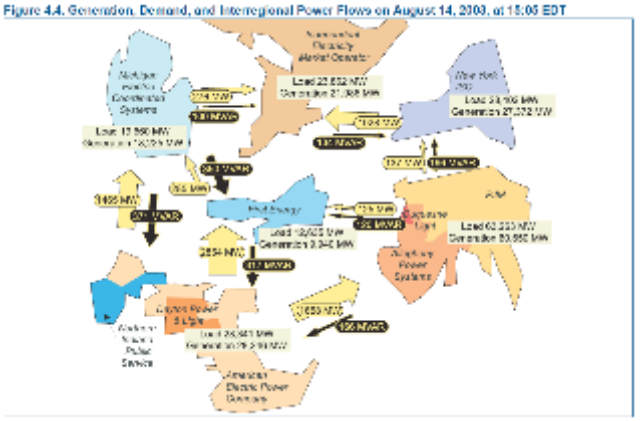


Figure 6.30. Cascade Sequence

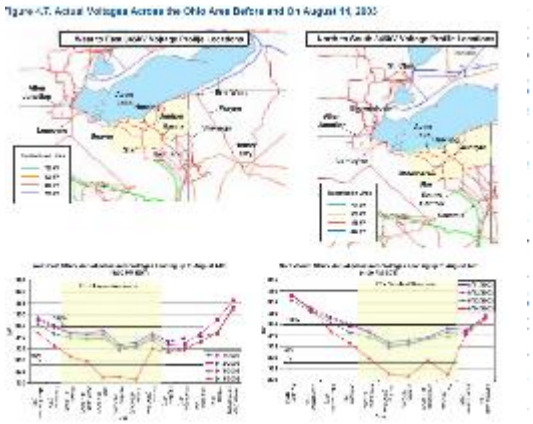
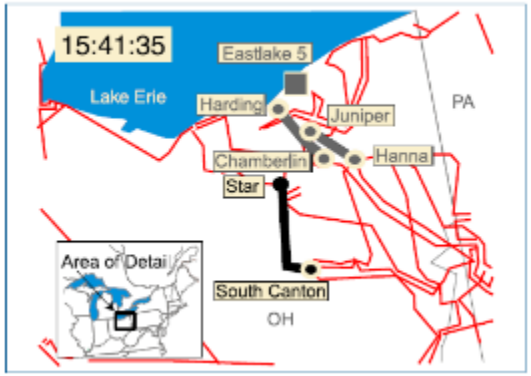
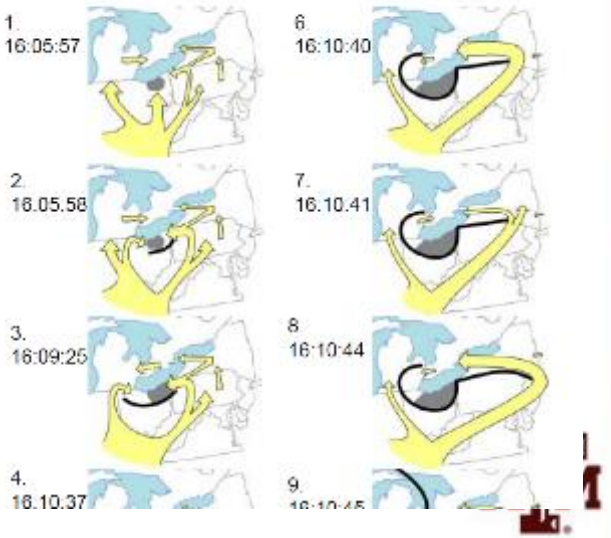


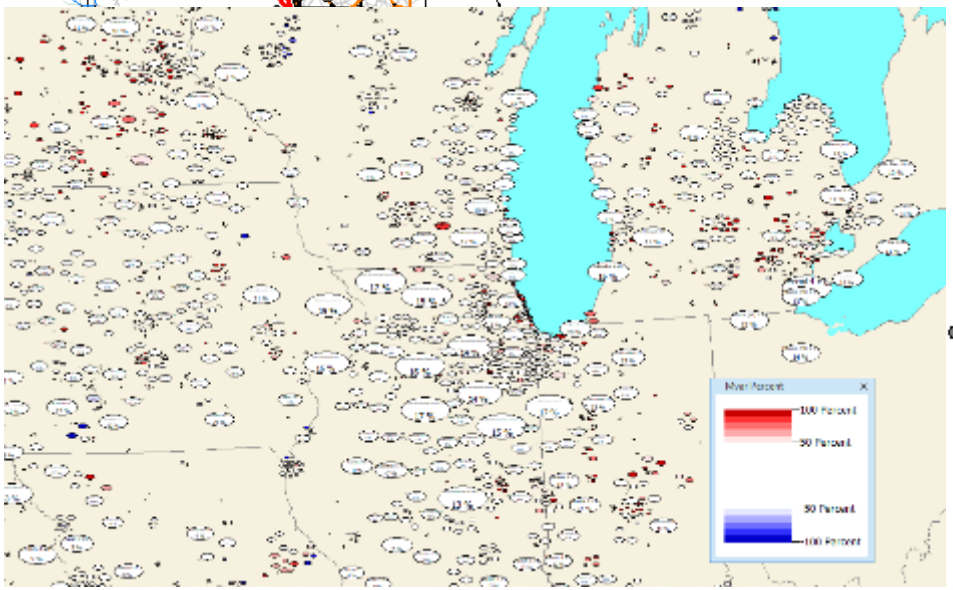
Figure 5.11. Star-South Canton 345-kV Line

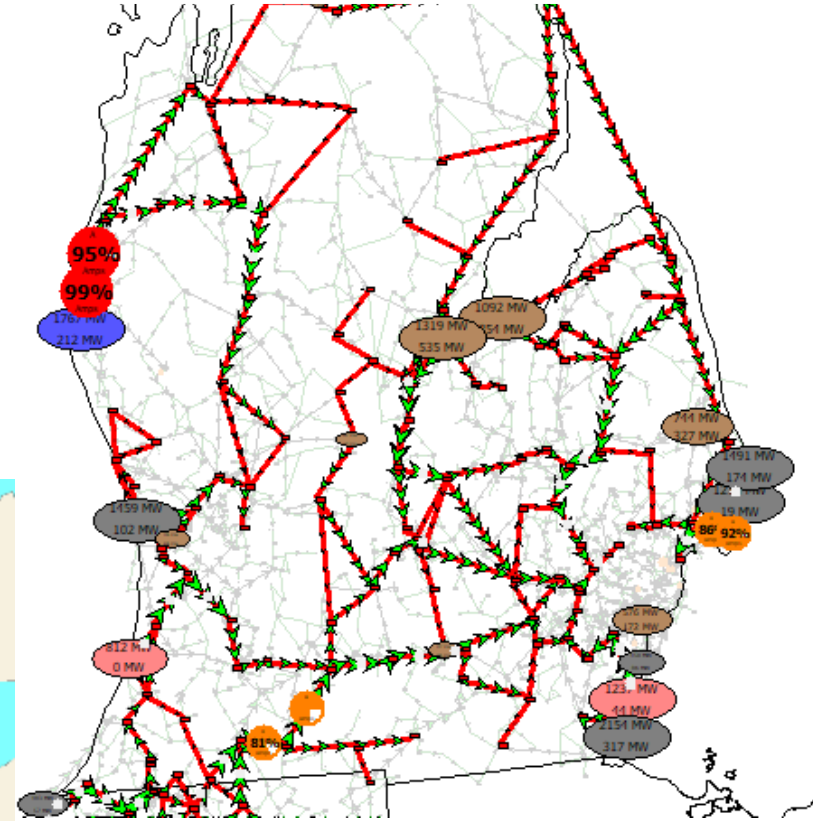




www.energy.gov/sites/default/files/oeprod/DocumentsandMedia/BlackoutFinal-Web.pdf

24K Grid Examples for Story Slices (from Farnaz Safdarian)

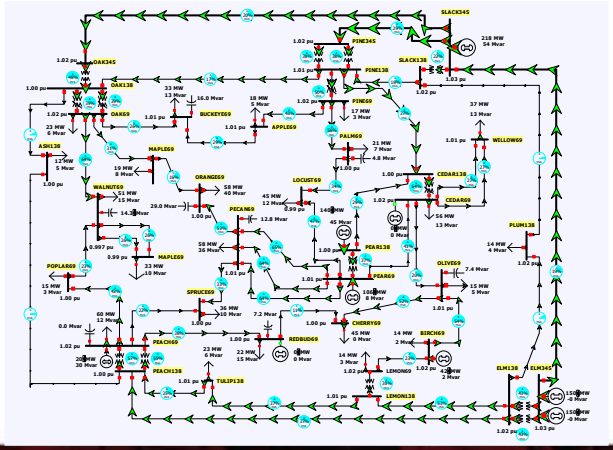


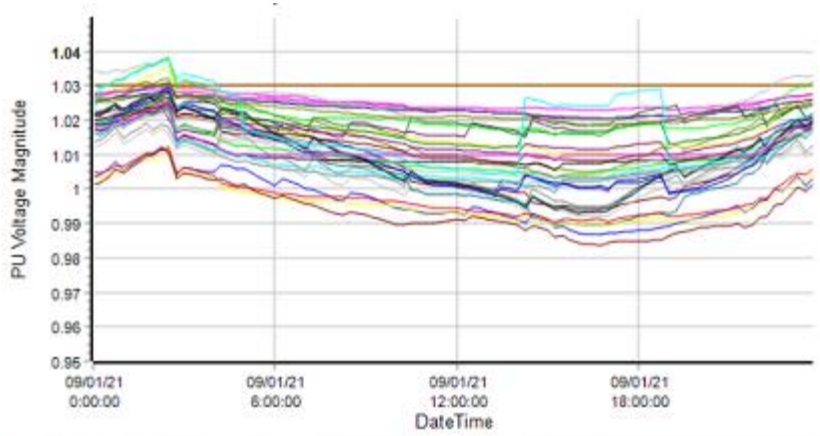


A Short 37-Bus Example
24 Hour Grid Narrative (Jess Wert)

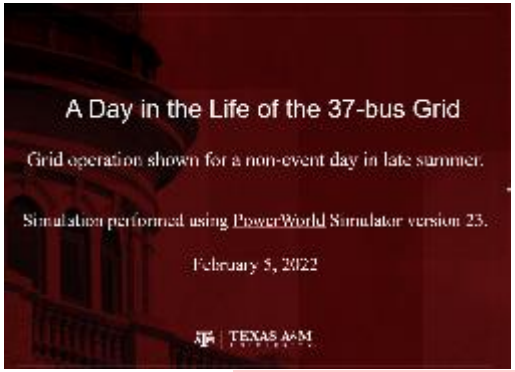
Audience: People with some grid knowledge with visualization but none with this grid. Goal is to provide an short example of grid storytelling.

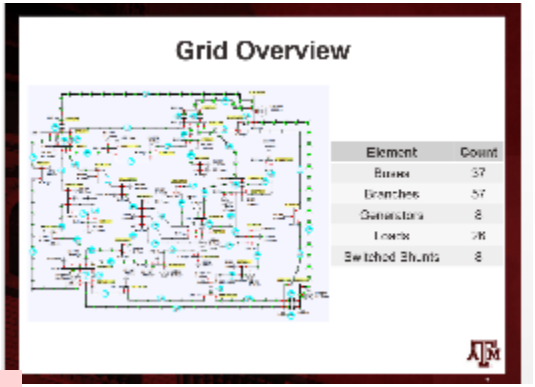
Story Slice	Story Element Block	Purpose	Approach	Duration (s)
1	Introduction to the Day in the Life of the Grid	Provide education on this narrative technique	Text description	5
2	Introduction to the 37-bus grid	Show system element information	System diagrams and tables are presented	10
3	Scenario Description	Introduce scenario and key events	Charts and text are used to provide a scenario overview	5
4	Animation of Voltage Contour (Linear Time)	Show system behavior through a voltage lens	Voltage contour on system diagram, jpeg snapshotsare presented linearly	12
5	Animation of Voltage Contour (Non-Linear Time)	Show system behavior through a voltage lens,emphasizing the peak load period	Voltage contour on system diagram, jpeg snapshotsare presented non-linearly	13
6	Pseudogeographic Mosaic Display (PGMD) Animation	Show system with a line loading lens	PGMD jpeg snapshots presented linearly	12

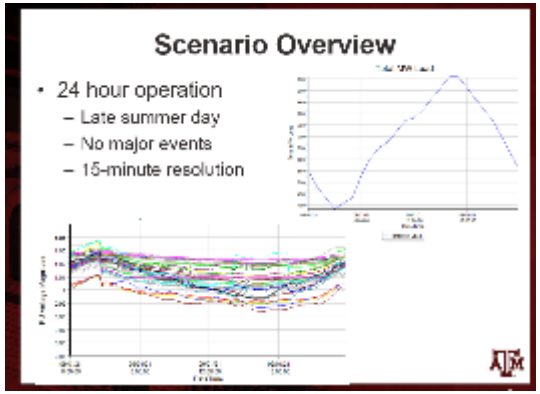




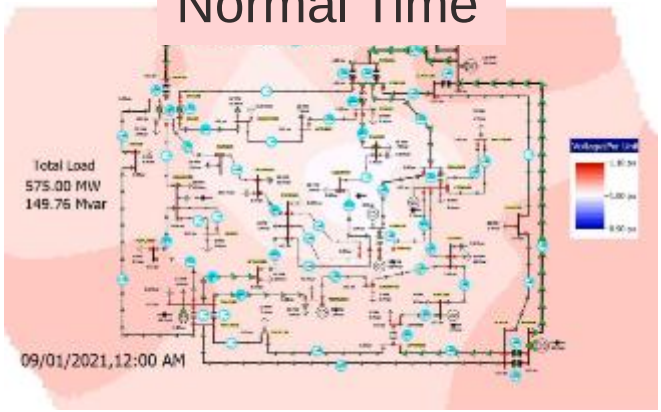
37-Bus Example Story Slices



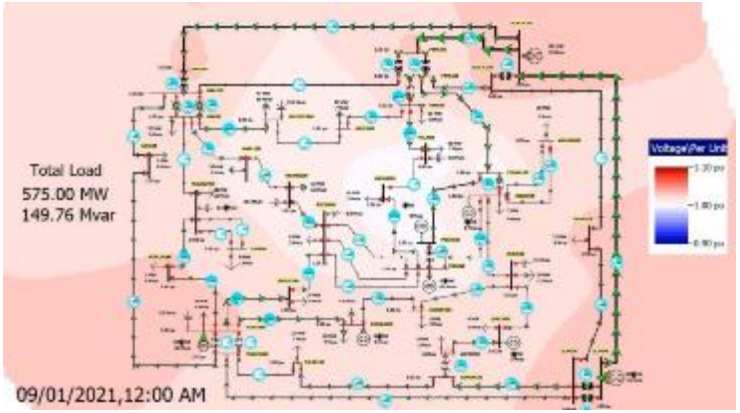




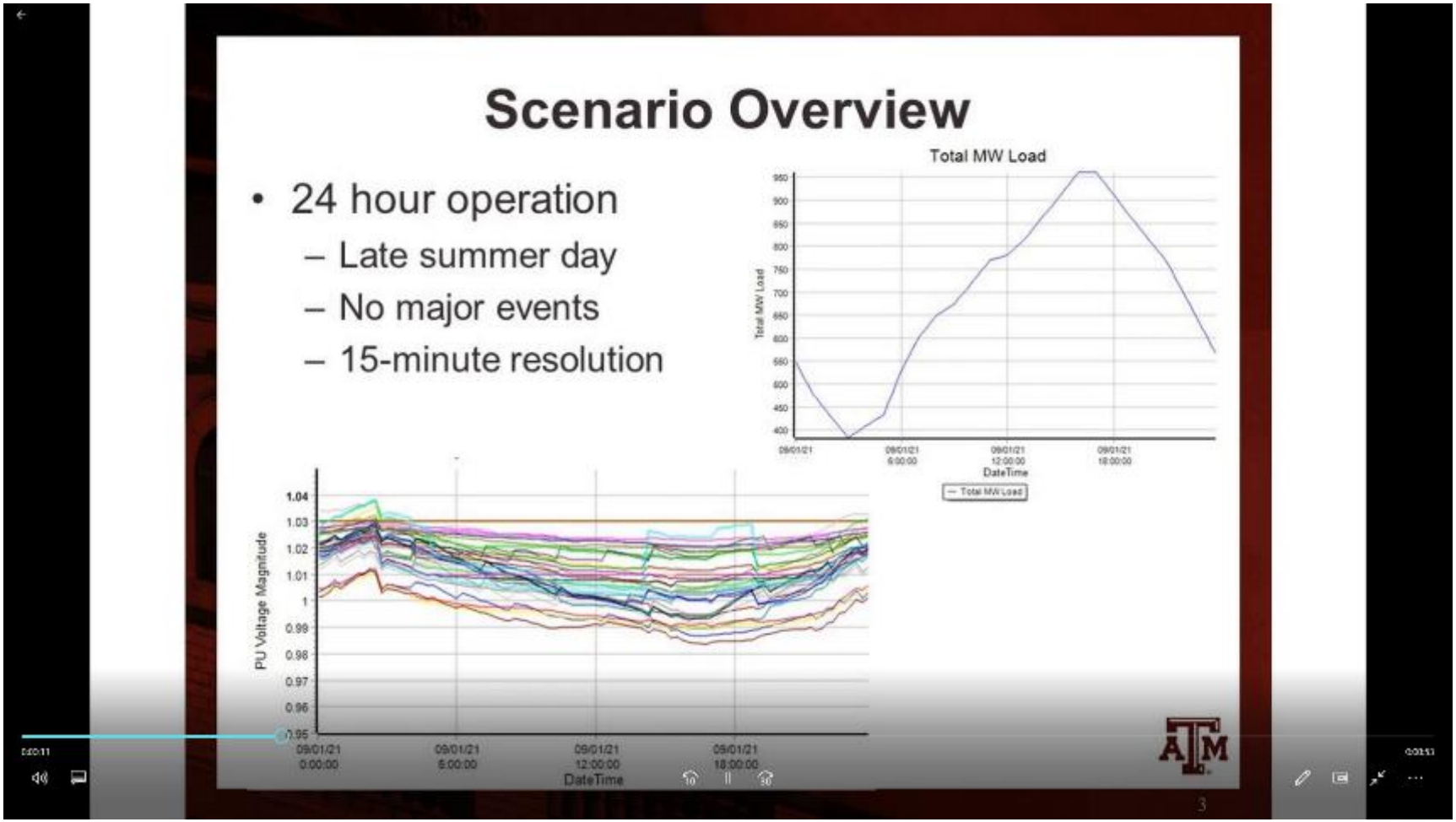
Normal Time



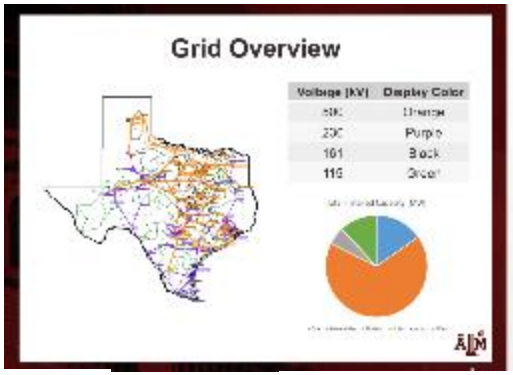
Variable Time

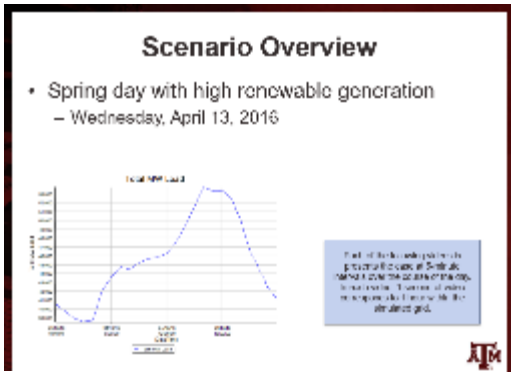


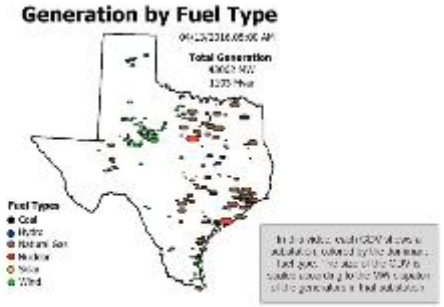
37-Bus Example Story Video

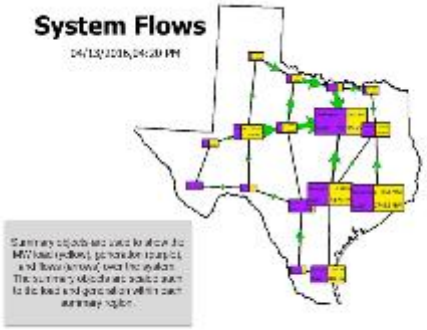


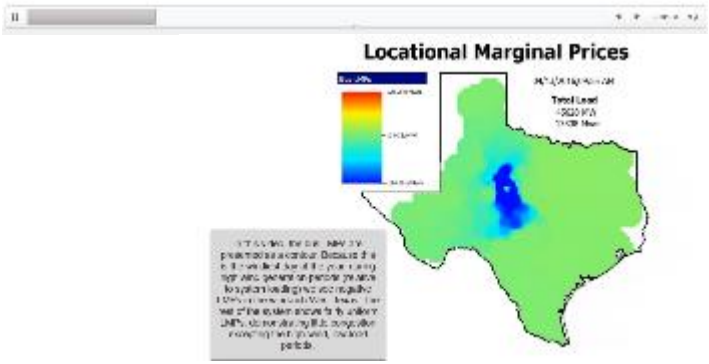
A Synthetic 2000 Bus Example

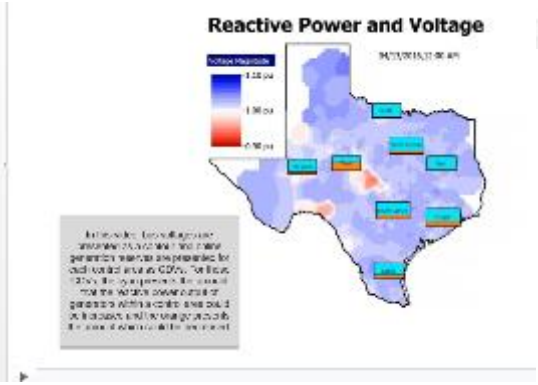




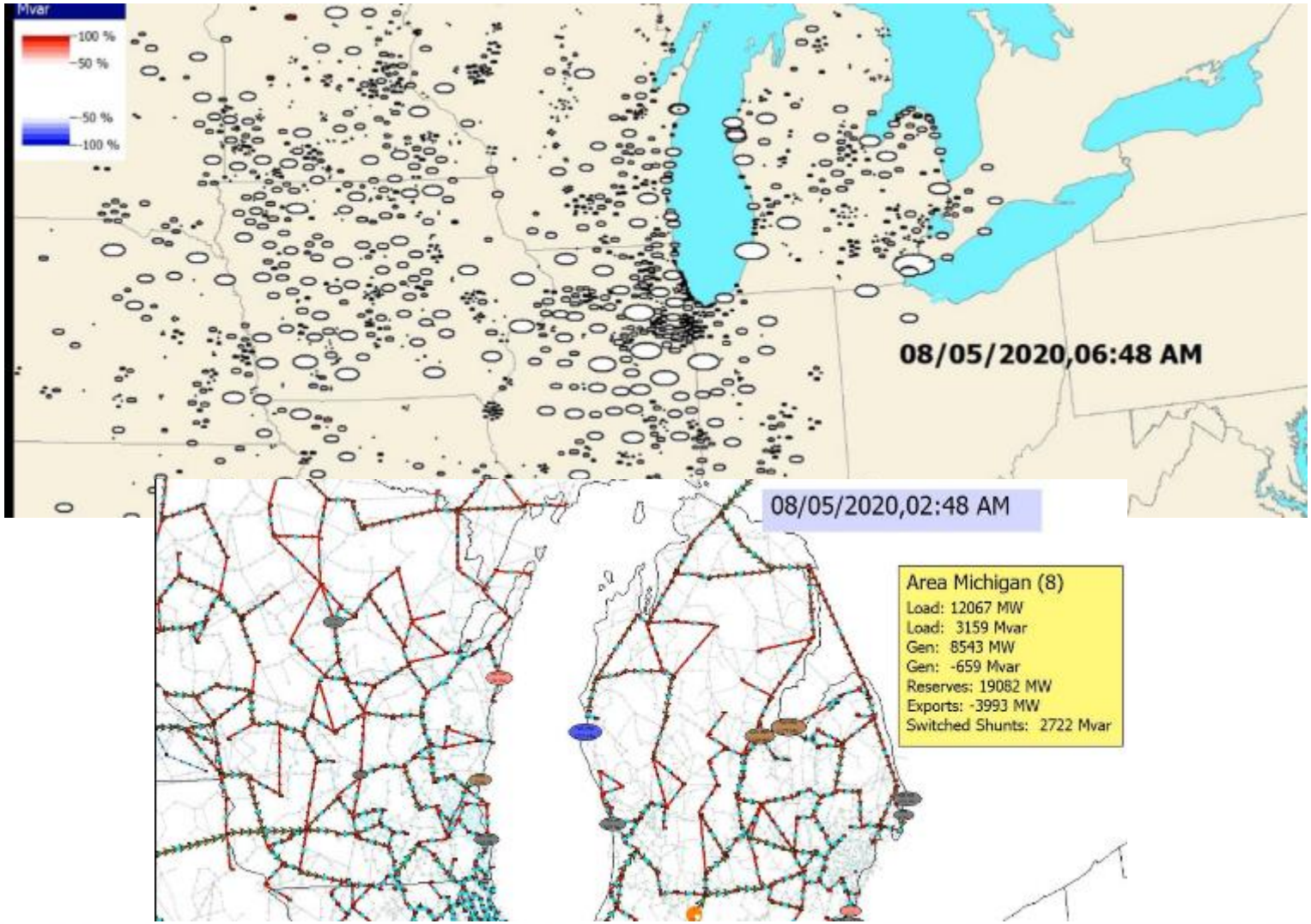








Story Slices from the 24,000 Bus Grid (Farnaz Safdarian)



Summary

- Electric grids have many stories that can be told, past, present and future
- How to tell these stories is a topic that is seldom discussed
- This presentation has provided at least some coverage of electric grid storytelling, focusing on the automatic development of shorter videos
- Using mostly existing techniques these stories can be developed and effectively told
- We would like to help you tell your electric grid story!

Thank You! Questions?

We hope you can join us in person on April 22, 2022 for Research Day at the A&M Center for Infrastructure Renewal in Bryan, TX;
required registration at smartgridcenter.tamu.edu

Some additional papers are available at overbye.engr.tamu.edu/publications/