Synthetic Power Grid Models: What are They, How They're Made, and Why They Matter

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Acknowledgments and Thanks

- Work presented in these slides is based on the results of several projects including
  - PSERC S-62G (Seamless Bulk Electric Grid Management with EPRI)
  - PSERC T-57 (High Impact)
  - BPA project TIP 353 (Improving Operator Situation Awareness by PMU Data Visualization
  - ARPA-E Grid Data Synthetic Data for Power Grid R&D
- Support is gratefully acknowledged!
  - Thanks also to Adam Birchfield, Kathleen Gegner, Ti Xu, Komal Shetye, Richard Macwan, Profs Bob Thomas, Anna Scaglione, Zhifang Wang and Ray Zimmerman

Presentation Overview

- Access to data about the actual power grid is often restricted because of requirements for data confidentiality (e.g., critical energy infrastructure)
    - Focus here is on high voltage power flow, optimal power flow, transient stability models, SCADA, PMUs
    - Some data is public, some is available by NDAs, and some is essentially unavailable to those outside of power system control centers
- Focus of talk is on the creation of synthetic (fictional) models that mimic the complexity of the actual grid cases but will contain no confidential data and can be publicly available

A Few Initial Thoughts

- The reason why this matters is to help spur innovation in the electric grid software
  - Algorithms tested on synthetic models applied to actual
- In 2000 the NAE named Electrification (the vast networks of electricity that power the developed world) as the top engineering technology of the 20th century
  - automobiles (2), airplanes (3), water (4), electronics (5)
- Our challenge in this century is to develop a sustainable and resilient electric infrastructure for the entire world

A Few Initial Thoughts

- "All models are wrong but some are useful,“

  George Box, *Empirical Model-Building and Response Surfaces*, (1987, p. 424)

- “The use of nondisclosure agreements or NDA’s to obtain data, while useful in many instances, is not useful if the world community is to engage in research that adheres to the scientific principle of reproducibility of results by other qualified researchers and to use important findings to advance their own work“

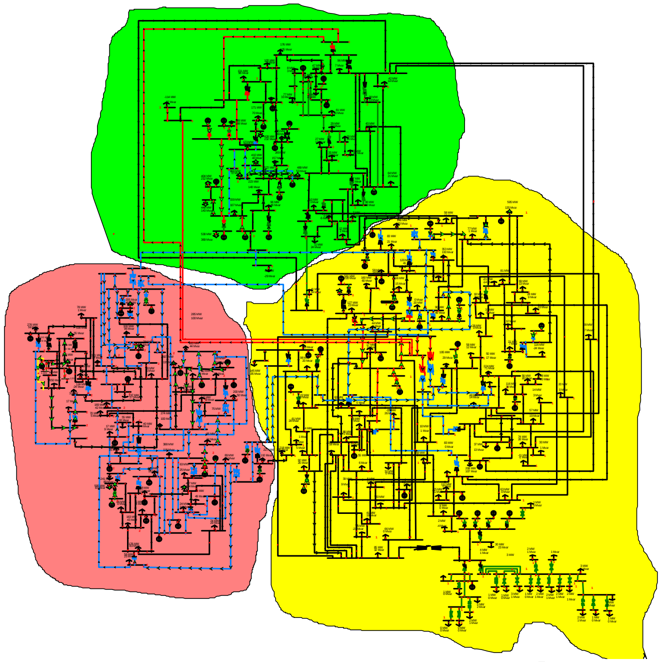
  PSERC Founding Director Bob Thomas, 2015

Overall Goals

- The development of entirely synthetic transmission system models and scenarios that match the complexity and variety of the actual grid
  - Models that incorporate both the average characteristics and outlier characteristics of the actual grid
  - Models and scenarios suitable for security constrained optimal power flow (SCOPF) studies; they will also be set for use in transient stability and geomagnetic disturbance analysis
  - All models will have embedded geographic coordinates
  - Scenarios will be SCOPF validated
- We want to partner with industry!

The Need

- Few, if any, of the existing public models (such as the IEEE 300 bus) match the complexity of the models used for actual large-scale grids

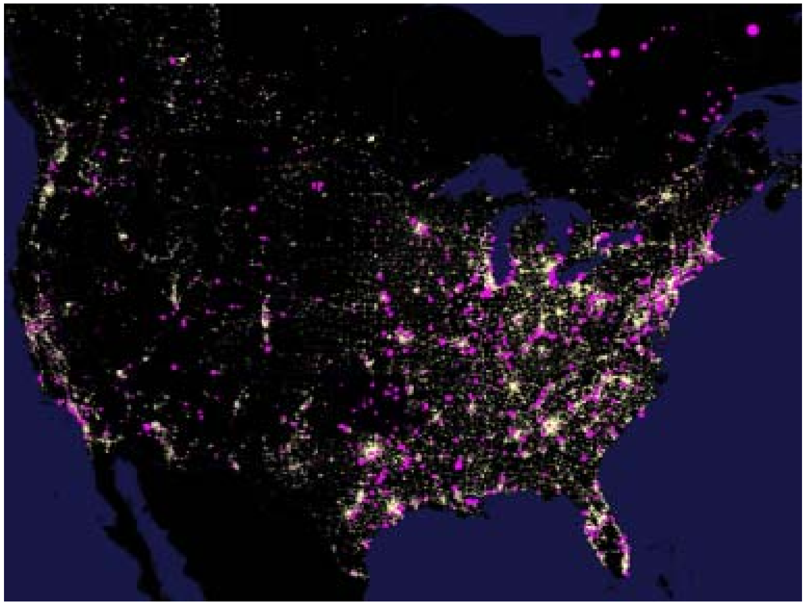


- Issues include size, with the Eastern Interconnect models now more than 70,000 buses, and also model complexity
    - Public models also lack extra data like transient stability
- Innovation is hindered by not being able to compare results for complex models

Image: IEEE 300 Bus case downloaded from http://icseg.iti.illinois.edu/ieee-300-bus-system/

What Makes a Model Real?

- The challenge is to capture the essence of what makes actual grid models different
  - Actual grid models are quite diverse



- Statistics can be used to quantify some of the characteristics
  - topology, parameters for buses, generators, loads, transmission lines, transformers, switched shunts, transient stability and GMD parameters
- System-wide metrics are also needed

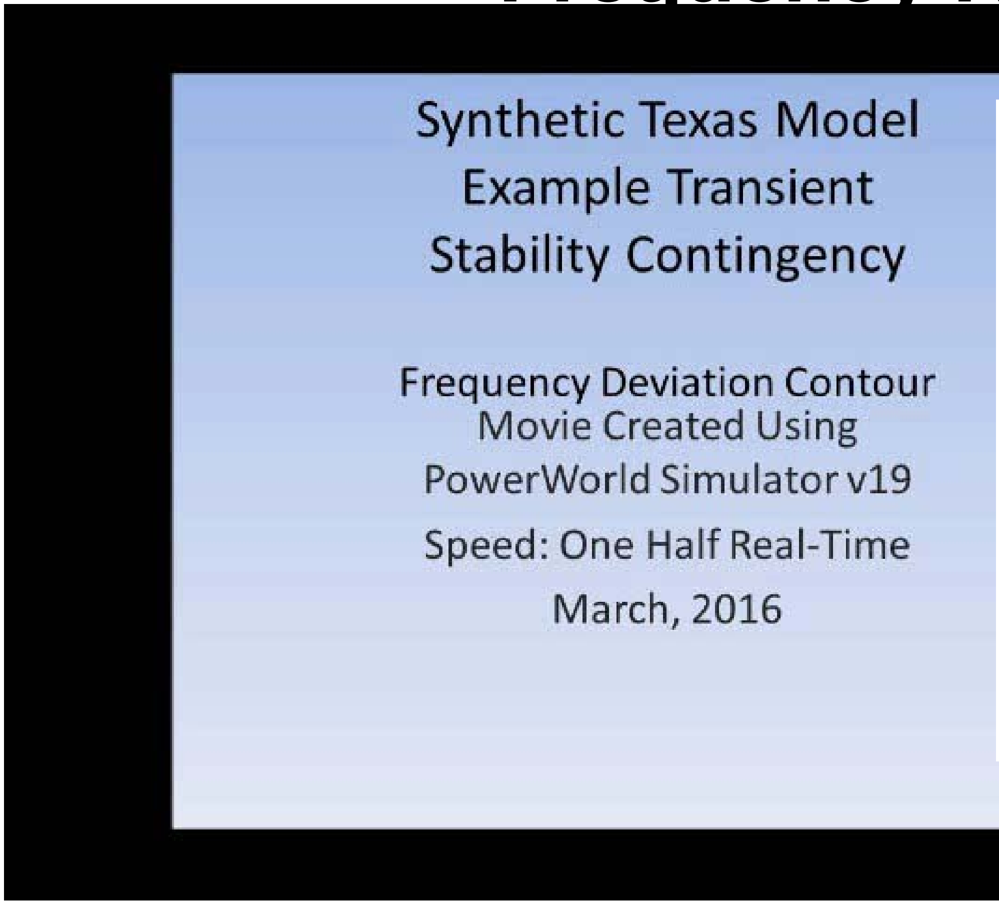
Complexity Examples

- A recent 76,000 bus Eastern Interconnect (EI) power flow model has 27,622 transformers including 98 phase shifters
  - Impedance correction tables are used for 351, including about 2/3 of the phase shifters; tables can change the impedance by more than two times over the tap range
- The voltage magnitude is controlled at about 19,000 buses (by Gens, LTCs, switched shunts)
  - 94% regulate their own terminals with about 1100 doing remote regulation. Of this group 572 are regulated by two or more devices, 277 by three or more, twelve by eight or more, and three by twelve devices!

How to Make Realistic, Geographically-Based, Synthetic Models

- Our approach is to make models that look real and familiar by siting these synthetic models in North America, and serving a population density the mimics that of North America
  - The transmission grid is, however, totally fictitious
- Goal is to leverage widely available public data:
  - Geography
  - Population density (easily available by post office)
  - Load by utility (FERC 714) and state-wide averages
  - Existing and planned generation: Form EIA-860 contains information about generators 1 MW and larger; data includes location, capacity and fuel type

Example: 2100 Bus Texas Case Frequency Response

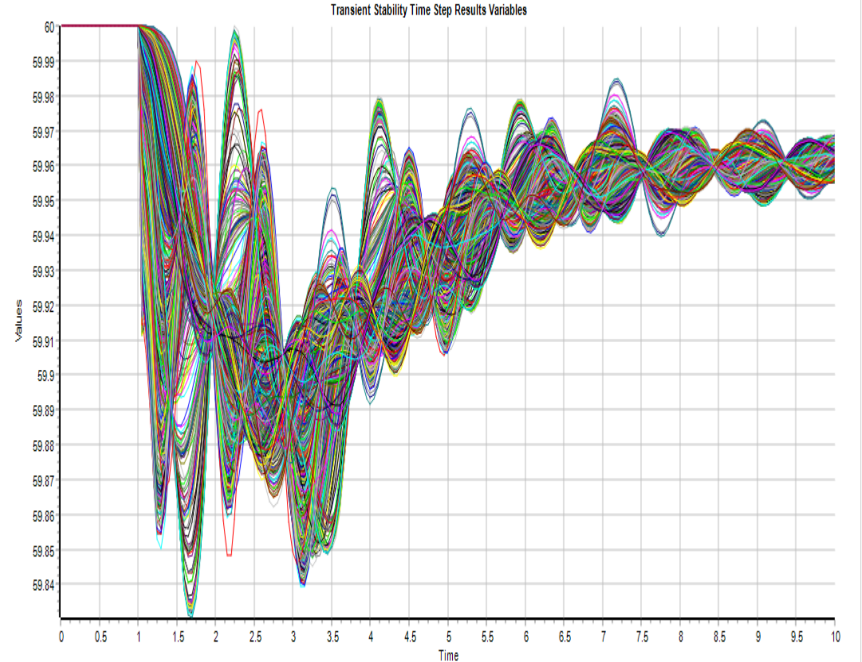


Synthetic Texas Model
Example Transient
Stability Contingency

Frequency Deviation Contour
Movie Created Using
PowerWorld Simulator v19

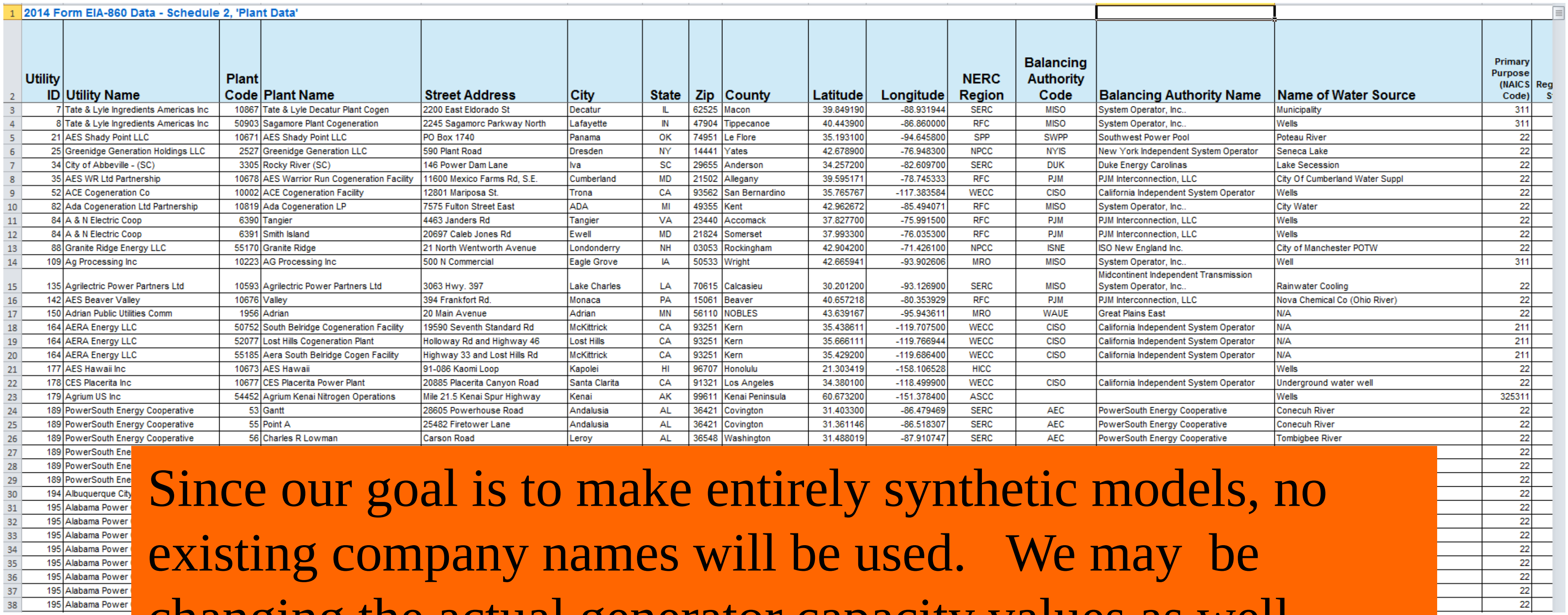
Speed: One Half Real-Time

March, 2016



EIA-860 Generator Data

- Online at www.eia.gov/electricity/data/eia860/



1 2014 Form EIA-860 Data - Schedule 2, 'Plant Data'

2	Utility ID	Utility Name	Plant Code	Plant Name	Street Address	City	State	Zip	County	Latitude	Longitude	NERC Region	Balancing Authority Code	Balancing Authority Name	Name of Water Source	Primary Purpose (NAICS Code)	Reg S
3	7	Tate & Lyle Ingredients Americas Inc	10867	Tate & Lyle Decatur Plant Cogen	2200 East Eldorado St	Decatur	IL	62525	Macon	39.849190	-88.931944	SERC	MISO	System Operator, Inc..	Municipality	311	
4	8	Tate & Lyle Ingredients Americas Inc	50903	Sagamore Plant Cogeneration	2245 Sagamorc Parkway North	Lafayette	IN	47904	Tippecanoe	40.443900	-86.860000	RFC	MISO	System Operator, Inc..	Wells	311	
5	21	AES Shady Point LLC	10671	AES Shady Point LLC	PO Box 1740	Panama	OK	74951	Le Flore	35.193100	-94.645800	SPP	SWPP	Southwest Power Pool	Poteau River	22	
6	25	Greenidge Generation Holdings LLC	2527	Greenidge Generation LLC	590 Plant Road	Dresden	NY	14441	Yates	42.678900	-76.948300	NPCC	NYIS	New York Independent System Operator	Seneca Lake	22	
7	34	City of Abbeville - (SC)	3305	Rocky River (SC)	146 Power Dam Lane	Iva	SC	29655	Anderson	34.257200	-82.609700	SERC	DUK	Duke Energy Carolinas	Lake Secession	22	
8	35	AES WR Ltd Partnership	10678	AES Warrior Run Cogeneration Facility	11600 Mexico Farms Rd, S.E.	Cumberland	MD	21502	Allegany	39.595171	-78.745333	RFC	PJM	PJM Interconnection, LLC	City Of Cumberland Water Suppl	22	
9	52	ACE Cogeneration Co	10002	ACE Cogeneration Facility	12801 Mariposa St.	Trona	CA	93562	San Bernardino	35.765767	-117.383584	WECC	CISO	California Independent System Operator	Wells	22	
10	82	Ada Cogeneration Ltd Partnership	10819	Ada Cogeneration LP	7575 Fulton Street East	ADA	MI	49355	Kent	42.962672	-85.494071	RFC	MISO	System Operator, Inc..	City Water	22	
11	84	A & N Electric Coop	6390	Tangier	4463 Janders Rd	Tangier	VA	23440	Accomack	37.827700	-75.991500	RFC	PJM	PJM Interconnection, LLC	Wells	22	
12	84	A & N Electric Coop	6391	Smith Island	20697 Caleb Jones Rd	Ewell	MD	21824	Somerset	37.993300	-76.035300	RFC	PJM	PJM Interconnection, LLC	Wells	22	
13	88	Granite Ridge Energy LLC	55170	Granite Ridge	21 North Wentworth Avenue	Londonderry	NH	03053	Rockingham	42.904200	-71.426100	NPCC	ISNE	ISO New England Inc.	City of Manchester POTW	22	
14	109	Ag Processing Inc	10223	AG Processing Inc	500 N Commercial	Eagle Grove	IA	50533	Wright	42.665941	-93.902606	MRO	MISO	System Operator, Inc..	Well	311	
15	135	Agrilectric Power Partners Ltd	10593	Agrilectric Power Partners Ltd	3063 Hwy. 397	Lake Charles	LA	70615	Calcasieu	30.201200	-93.126900	SERC	MISO	Midcontinent Independent Transmission System Operator, Inc..	Rainwater Cooling	22	
16	142	AES Beaver Valley	10676	Valley	394 Frankfort Rd.	Monaca	PA	15061	Beaver	40.657218	-80.353929	RFC	PJM	PJM Interconnection, LLC	Nova Chemical Co (Ohio River)	22	
17	150	Adrian Public Utilities Comm	1956	Adrian	20 Main Avenue	Adrian	MN	56110	NOBLES	43.639167	-95.943611	MRO	WAUE	Great Plains East	N/A	22	
18	164	AERA Energy LLC	50752	South Belridge Cogeneration Facility	19590 Seventh Standard Rd	McKittrick	CA	93251	Kern	35.438611	-119.707500	WECC	CISO	California Independent System Operator	N/A	211	
19	164	AERA Energy LLC	52077	Lost Hills Cogeneration Plant	Holloway Rd and Highway 46	Lost Hills	CA	93251	Kern	35.666111	-119.766944	WECC	CISO	California Independent System Operator	N/A	211	
20	164	AERA Energy LLC	55185	Aera South Belridge Cogen Facility	Highway 33 and Lost Hills Rd	McKittrick	CA	93251	Kern	35.429200	-119.686400	WECC	CISO	California Independent System Operator	N/A	211	
21	177	AES Hawaii Inc	10673	AES Hawaii	91-086 Kaomi Loop	Kapolei	HI	96707	Honolulu	21.303419	-158.106528	HICC			Wells	22	
22	178	CES Placerita Inc	10677	CES Placerita Power Plant	20885 Placerita Canyon Road	Santa Clarita	CA	91321	Los Angeles	34.380100	-118.499900	WECC	CISO	California Independent System Operator	Underground water well	22	
23	179	Agrium US Inc	54452	Agrium Kenai Nitrogen Operations	Mile 21.5 Kenai Spur Highway	Kenai	AK	99611	Kenai Peninsula	60.673200	-151.378400	ASCC			Wells	325311	
24	189	PowerSouth Energy Cooperative	53	Gantt	28605 Powerhouse Road	Andalusia	AL	36421	Covington	31.403300	-86.479469	SERC	AEC	PowerSouth Energy Cooperative	Conecuh River	22	
25	189	PowerSouth Energy Cooperative	55	Point A	25482 Firetower Lane	Andalusia	AL	36421	Covington	31.361146	-86.518307	SERC	AEC	PowerSouth Energy Cooperative	Conecuh River	22	
26	189	PowerSouth Energy Cooperative	56	Charles R Lowman	Carson Road	Leroy	AL	36548	Washington	31.488019	-87.910747	SERC	AEC	PowerSouth Energy Cooperative	Tombigbee River	22	
27	189	PowerSouth Ene														22	
28	189	PowerSouth Ene														22	
29	189	PowerSouth Ene														22	
30	194	Albuquerque City														22	
31	195	Alabama Power														22	
32	195	Alabama Power														22	
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37	195	Alabama Power														22	
38	195	Alabama Power														22	

Since our goal is to make entirely synthetic models, no existing company names will be used. We may be changing the actual generator capacity values as well.

How to Make Realistic Synthetic Models

- First step is to select a desired size (bus count) and geographic footprint
  - These are two independent parameters: for example, geographically large with a small number of buses
  - Our approach does not require that we use actual geography; however most, if not all, of our models will
  - Requires an assumption on underlying load density
  - Nominal transmission voltages need to be selected (e.g., 500/230/115 kV); we will allow multiple levels
  - On larger models the geographic footprint is divided into balancing authority areas and fictitious owners

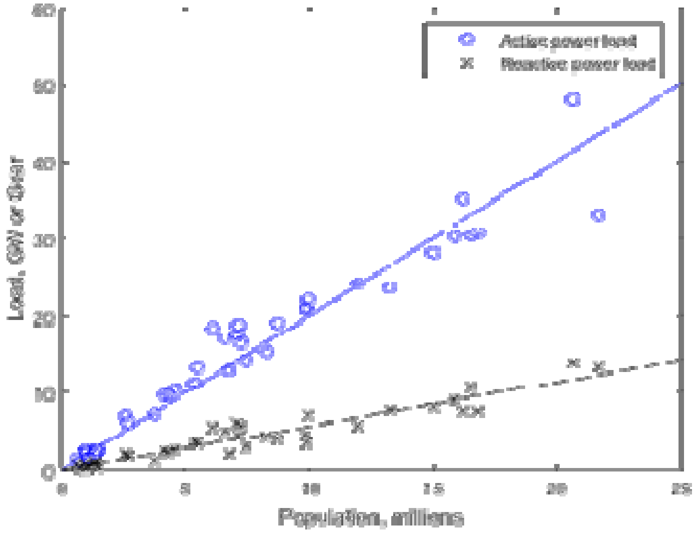
How to Make Realistic Synthetic Models: Substation Selection

- The next step is to site the substations
  - Buses are located in substations; number of buses in a substation can vary widely
  - Most substations have load and/or generation; number of buses can depend on model assumptions, such as whether generator step-up transformers are modeled
- Substation are sited geographically primarily in order to meet load and generation requirements
  - One approach for the assumed load density is mimic population density as given by zip code information
  - Number of substation depends on the desired model size; in actual models the amount of substation load can widely vary (from 1 MW to more than 500 MW)

How to Make Realistic Synthetic Models: Substation Selection

- In our approach substations are placed geographically at post offices
- The load is proportional to population, taking into account state variation
- Hierarchical clustering is used to reduce the number of substations as needed
- Load is usually attached at lowest-voltage bus

Load vs Population
in 37 Eastern U.S. States

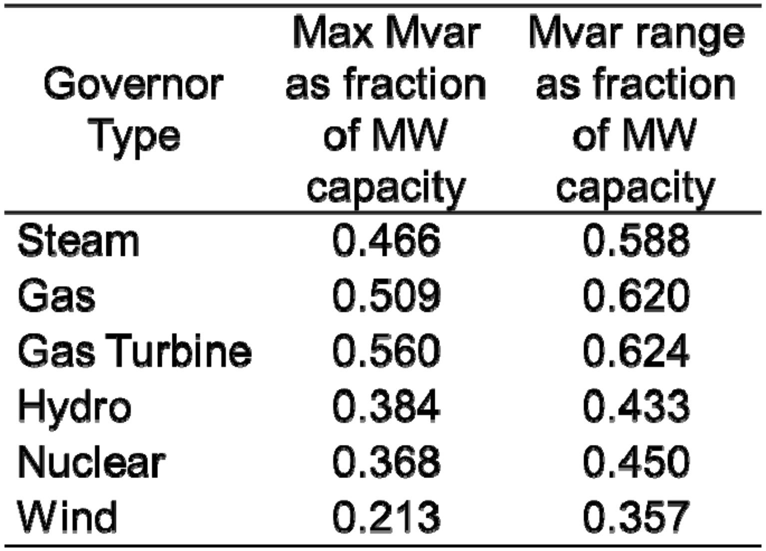


2.00 kW/capita
0.57 kvar/capita

Generator Substation Placement

- Based on actual model statistics, some generation is located at existing load substations
- Other plants are combined into generator-only substations
- Generator parameters, including reactive power limits and cost information, are derived from statistics
- Transient stability models are added

Statistics derived from real power system case



Governor Type	Max Mvar as fraction of MW capacity	Mvar range as fraction of MW capacity
Steam	0.466	0.588
Gas	0.509	0.620
Gas Turbine	0.560	0.624
Hydro	0.384	0.433
Nuclear	0.368	0.450
Wind	0.213	0.357

Substation Voltage Levels

- Each substation now has load/generation defined
  - Statistically about 90% in actual grid have load or gen
- Different system voltage levels are chosen
  - E.g., 500/161, 765/345/138, 500/230/115
- Almost all substations have lower voltage bus
- A percent of substations (e.g.,15%) also include higher voltage buses and transformers
- Higher-voltage substations are iteratively selected with probabilities proportional to load
- All large (> 250 MW) generators are placed at the higher voltage level, but with a GSU

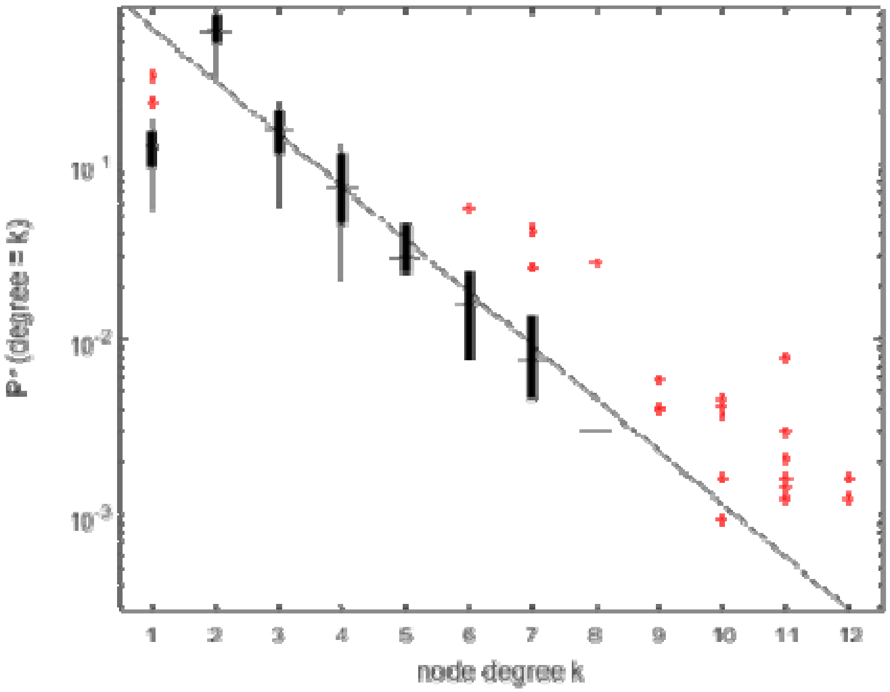
Adding Transmission Lines

- Substations are connected together by transmission lines, matching characteristics of actual models
  - Builds on pioneering work done by PSERC researchers Thomas, Wang and Scaglione
    - Z. Wang, R.J. Thomas, A. Scaglione, “Generating random topology power grids,” HICSS-41, HI, Jan 2008
    - Z. Wang, A. Scaglione and R.J. Thomas, “The Node Degree Distribution in Power Grid and Its Topology Robustness under Random and Selective Node Removals”, the 1st IEEE International Workshop on Smart Grid Communications, Cape Town, South Africa, May 2010
    - Z. Wang, R.J. Thomas, “On Bus Type Assignments in Random Topology Power Grid Models”, HICSS-48, Jan. 2015

Substation Node Degree (Number of Neighbors)

- Need to match statistics for number of connected substations at each voltage level
- Average nodal degree $\langle k \rangle = 2.43$, nearly constant with n for single-voltage networks in EI
- Number of lines $$m = \frac{\langle k \rangle n}{2} = 1.22n$$
- Node degree distribution appears to be exponential. $$\Pr(k) = 1.19e^{-0.69k}$$

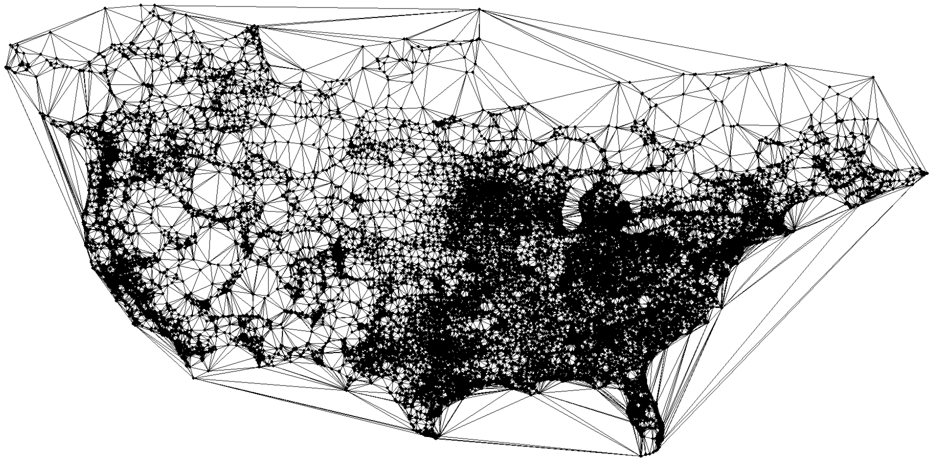
(except for k=1 and 2)

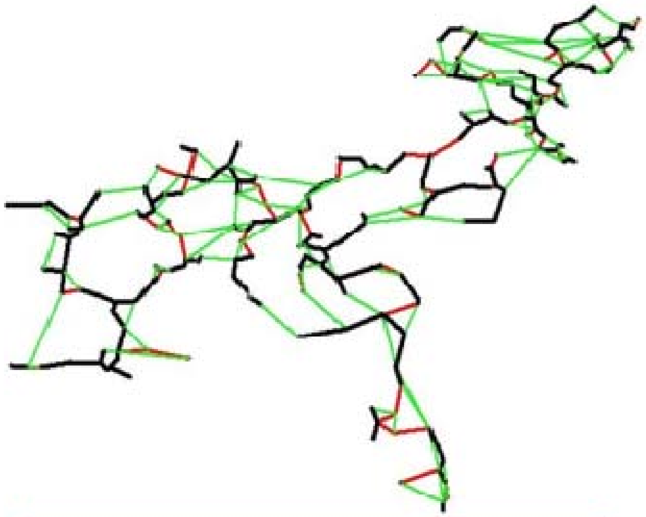


Adding Transmission Lines

- Graph theory considerations are used to determine which substations are connected
  - An approach is to do Delaunay triangulation along with minimum spanning tree (MST) analysis

Image shows Delaunay triangulation of 42,000 North America substations; statistics only consider single voltage levels; computationally fast (order n ln(n))





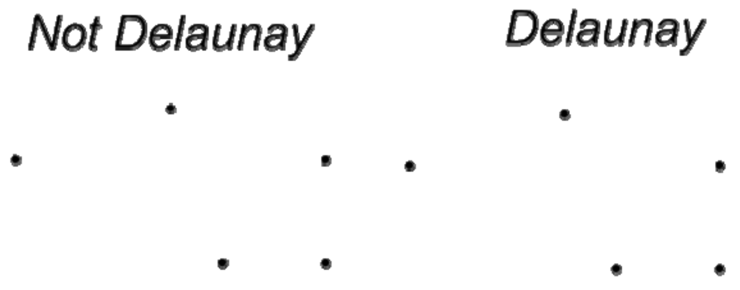
MST for the EI 500 kV grid; black actual on MST, green other

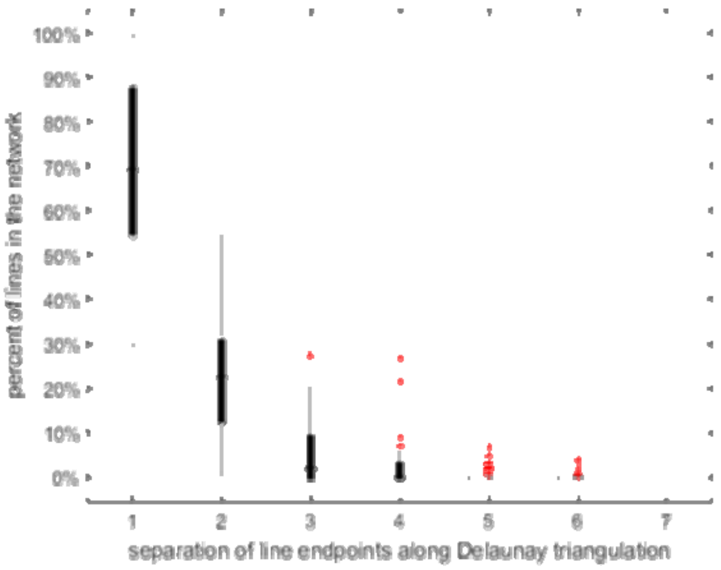
Adding Transmission Lines

- In general, transmission line topologies are totally connected, and remain so with one node removed
- Typical actual power system contains 60% of its substations' minimum spanning tree (MST) at each nominal voltage level (percent varies by voltage level)
- Approach is to match the MST percentage
- Then other lines are added to match the typical average ($1.22n$ edges per bus)

Using Delaunay Triangulation to Add Additional Lines

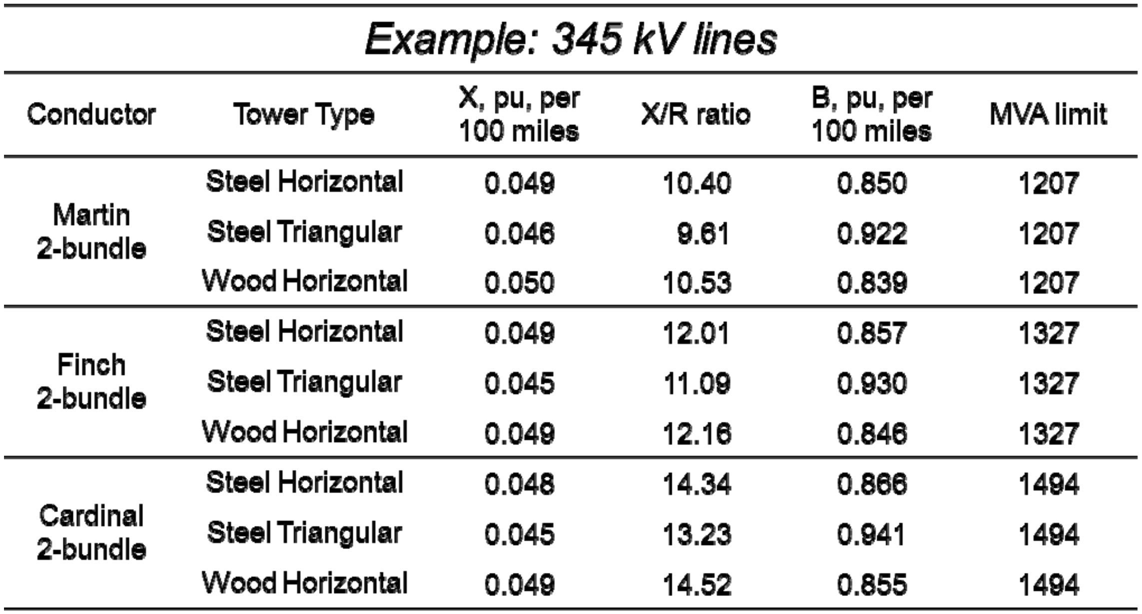
- Delaunay triangulation
  - No triangle’s circumcircle contains another point
  - Nearest few neighbors are connected
  - Statistics $\langle c \rangle$ and $\langle l \rangle$ match regular lattice and actual grid
- Contains 70% of real lines on average, and 98% separated by 3 hops or less
- We select subset out of Delaunay’s $3n$ segments





Transmission Line Parameters

- Transmission line parameters from EPRI & ACSR guides
- Different configurations for each voltage level:



Example: 345 kV lines

Conductor	Tower Type	X, pu, per 100 miles	X/R ratio	B, pu, per 100 miles	MVA limit
Martin 2-bundle	Steel Horizontal	0.049	10.40	0.850	1207
	Steel Triangular	0.046	9.61	0.922	1207
	Wood Horizontal	0.050	10.53	0.839	1207
Finch 2-bundle	Steel Horizontal	0.049	12.01	0.857	1327
	Steel Triangular	0.045	11.09	0.930	1327
	Wood Horizontal	0.049	12.16	0.846	1327
Cardinal 2-bundle	Steel Horizontal	0.048	14.34	0.866	1494
	Steel Triangular	0.045	13.23	0.941	1494
	Wood Horizontal	0.049	14.52	0.855	1494

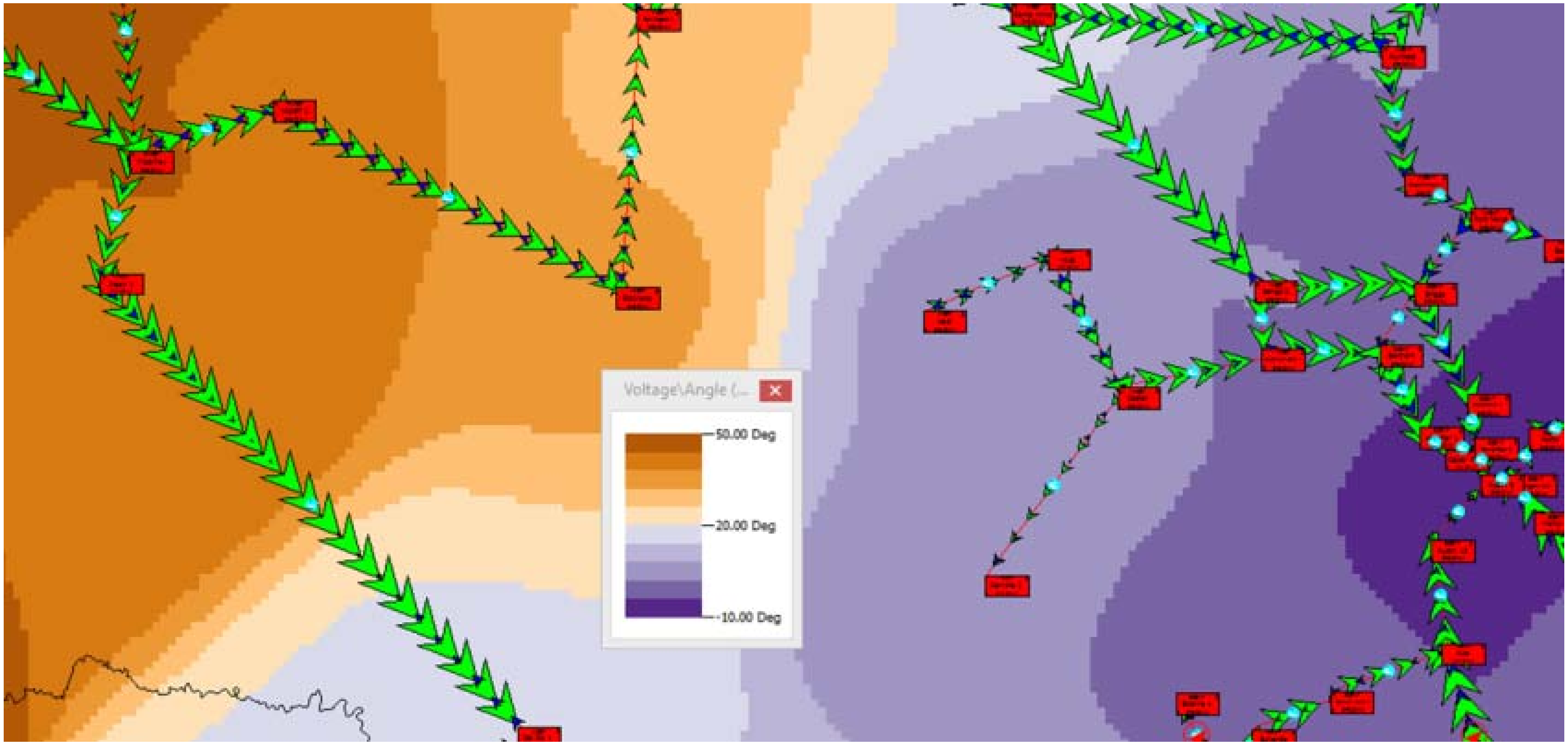
These parameters are validated against real transmission lines

Iterative Updates to Obtain a Feasible DC Power Flow Solution

- A connected graph allows dc power flow solutions
- Iteratively add lines to obtain a dc power flow with no line flow violations
- Candidate lines are segments of the Delaunay triangulation or near neighbors
- Place total of $1.22n$ lines per voltage level
- Select lines based on:
  - Voltage angle gradient, indicating likely power flow
  - Avoid radial substations
  - Encourage parallel circuits to overloaded lines
  - Forbid lines exceeding a maximum length

Example: Transmission Line Placement

- Based on voltage angle gradient, this might be a good location for a transmission line

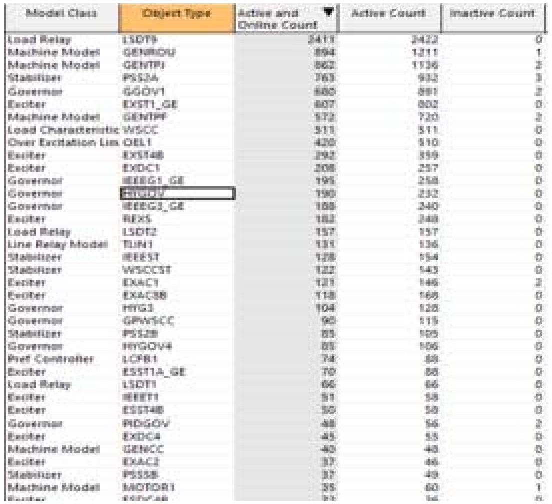


Reactive Compensation and Additional Model Complexity

- The next step is the specification of the generator PV bus setpoints, the inclusion of additional reactive power control devices such as switched shunts and LTC control, and the inclusion of additional complexities such tap dependent impedances (XF correction tables)
  - Realistic remote generator PV control will be modeled, including reactive power sharing among a number of generator
  - A hypothesis we are considering is that the difficulties encountered with actual models compared to public models, such as the IEEE 118 bus case, are due to these complexities

Model Creation Methodology: Inclusion of Additional Parameters

- The final step in the creation of the models themselves will be the inclusion of the models necessary to do transient stability and GMD analysis
- As with the other models, parameters will be set to match the statistics of the actual grid

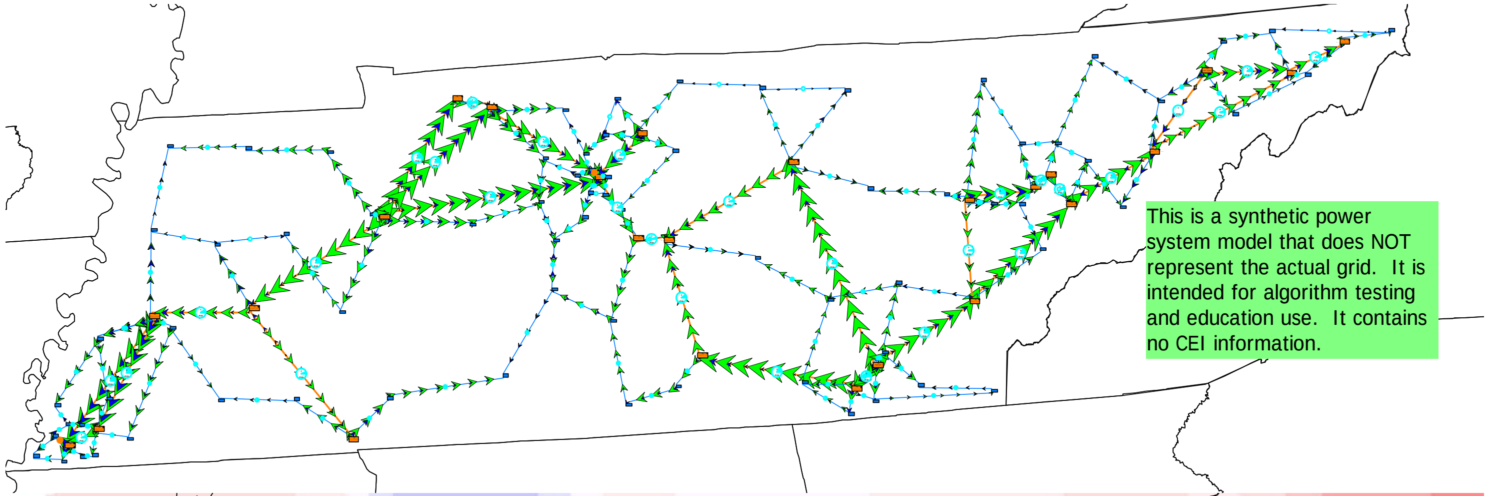


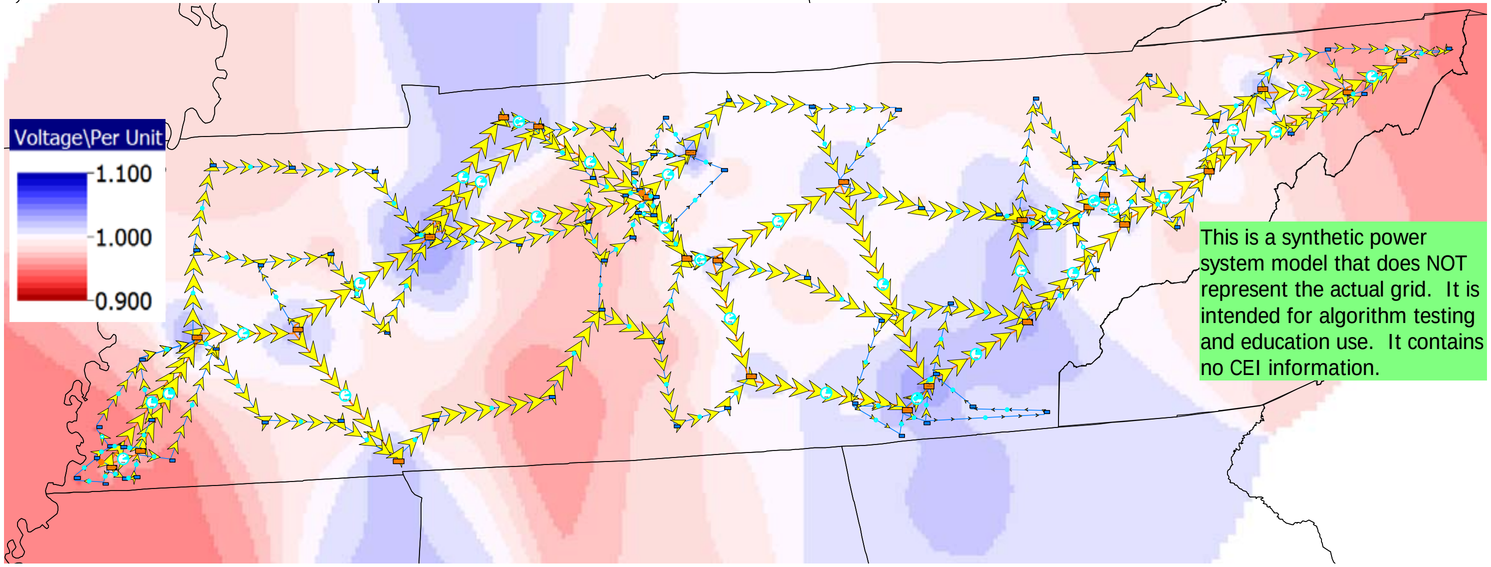
Model Class	Object Type	Active and Online Count	Active Count	Inactive Count
Load Relay	LSDT9	2411	2422	0
Machine Model	GENROU	894	1211	1
Machine Model	GENTPJ	862	1136	2
Stabilizer	PSS2A	763	932	3
Governor	GGOV1	680	891	2
Exciter	EXST1_GE	607	802	0
Machine Model	GENTPF	572	720	2
Load Characteristic	WSCC	511	511	0
Over Excitation Lim	OEL1	420	510	0
Exciter	EXST4B	292	359	0
Exciter	EXDC1	208	257	0
Governor	IEEEG1_GE	195	258	0
Governor	HYGOV	190	232	0
Governor	IEEEG3_GE	188	240	0
Exciter	REXS	182	248	0
Load Relay	LSDT2	157	157	0
Line Relay Model	TLIN1	131	136	0
Stabilizer	IEEEST	128	154	0
Stabilizer	WSCCST	122	143	0
Exciter	EXAC1	121	146	2
Exciter	EXAC8B	118	168	0
Governor	HYG3	104	128	0
Governor	GPWSCC	90	115	0
Stabilizer	PSS2B	85	105	0
Governor	HYGOV4	85	106	0
Pref Controller	LCFB1	74	88	0
Exciter	ESST1A_GE	70	88	0
Load Relay	LSDT1	66	66	0
Exciter	IEEET1	51	58	0
Exciter	ESST4B	50	58	0
Governor	PIDGOV	48	56	2
Exciter	EXDC4	45	55	0
Machine Model	GENCC	40	48	0
Exciter	EXAC2	37	46	0
Stabilizer	PSS3B	37	49	0
Machine Model	MOTOR1	35	60	1

Type	MVA Base	H	D	Ra	Xd	Xq	Xdp	Xqp	Xdpp	Xl	Tdop	Tqop	Tdopp	Tqopp	S1	S12	RComp	XComp
GENROU	58.822	4.22	0	0	1.73	1.6	0.285	0.8	0.2036	0.1	7.1	2	0.03	0.2	0.194	0.4597	0	0
GENROU	58.822	4.22	0	0	1.73	1.6	0.285	0.8	0.2036	0.1	7.1	2	0.03	0.2	0.194	0.4597	0	0
GENROU	88.235	4.22	0	0	1.76	1.52	0.24	0.7	0.2036	0.1	7	2	0.03	0.1	0.2196	0.6399	0	0
GENROU	410	3.71	0	0.004	1.7	1.4	0.24	0.33	0.21	0.17	5.5	0.51	0.05	0.06	0.1603	0.4861	0	0
GENROU	410	3.8	0	0.002	1.85	1.4	0.3088	0.33	0.2573	0.17	6.76	0.51	0.05	0.06	0.113	0.4049	0	0
GENROU	616.7	2.15	0	0	1.57	1.47	0.28	0.453	0.25	0.145	4.2	0.494	0.05	0.0583	0.135	0.432	0	0
GENROU	616.7	2.15	0	0	1.57	1.47	0.28	0.453	0.25	0.145	4	0.494	0.05	0.0583	0.135	0.432	0	0
GENROU	234	4.87	0	0	2.25	1.825	0.275	0.85	0.2264	0.15	9	0.9	0.036	0.07	0.09	0.2687	0	0
GENROU	234	4.87	0	0	2.25	1.825	0.275	0.85	0.2264	0.15	9	0.9	0.036	0.07	0.09	0.2687	0	0
GENROU	373	2.91	0	0	2.27	1.7	0.33	0.85	0.27	0.231	7.5	0.9	0.036	0.07	0.065	0.5795	0	0
GENROU	143.6	4.35	0	0.0028	1.445	1.382	0.22	0.375	0.185	0.11	5.97	0.52	0.039	0.086	0.0541	0.3602	0	0
GENROU	189	4.8	0	0.0025	1.77	1.662	0.235	0.4	0.195	0.12	7	0.539	0.055	0.083	0.0697	0.3761	0	0
GENROU	60	2.18	0	0.003	2.3	2.25	0.28	1.1	0.226	0.12	6.5	3	0.03	0.2	0.0727	0.3108	0	-0.05
GENROU	60	2.18	0	0.003	2.3	2.25	0.28	1.1	0.226	0.12	6.5	3	0.03	0.2	0.0727	0.3108	0	-0.05
GENROU	191	5.7	0	0.003	1.47	1.4	0.212	0.4	0.16	0.12	7.7	0.54	0.039	0.083	0.057	0.441	0	0
GENROU	89.5	6.96	0	0	2.04	1.8	0.278	0.7	0.239	0.19	8.2	1	0.05	0.05	0.1	0.327	0	0
GENROU	96	3.8	0	0	1.6	1.48	0.22	0.9	0.173	0.16	6	0.6	0.03	0.06	0.104	0.516	0	0
GENROU	96	3.54	0	0	1.6	1.5	0.226	0.4	0.19	0.15	8	1	0.025	0.0255	0.094	0.43	0	0
GENROU	135.3	3.21	0	0	1.56	1.4	0.255	0.5	0.22	0.15	8.5	1	0.03	0.09	0.085	0.5557	0	0
GENROU	94.444	6.6	0	0	1.54	1.45	0.324	0.7	0.26	0.2	8	1	0.05	0.05	0.2125	1.0058	0	0
GENROU	94.444	6.6	0	0	1.54	1.45	0.324	0.7	0.26	0.2	8	1	0.05	0.05	0.2125	1.0058	0	0
GENROU	133.333	3.58	0	0	1.48	1.2	0.26	0.45	0.18	0.144	10.5	1	0.05	0.05	0.1368	0.676	0	0
GENROU	58.822	4.7	0	0	1.55	1.3	0.256	0.4	0.181	0.15	6.7	1	0.03	0.1	0.16	0.5	0	0
GENROU	58.825	3	0	0	1.7	1.3	0.25	0.6	0.22	0.19	7	0.4	0.025	0.05	0.1808	0.5840	0	0
GENROU	185	4.43	0	0	1.5	1.3	0.16	0.6	0.14	0.1	10	0.7	0.05	0.08	0.0578	0.3644	0	0
GENROU	101.8	5.63	0	0.003	2.03	1.856	0.16	0.3	0.12	0.08	12.5	3.9	0.05	0.05	0.162	0.789	0	0
GENROU	101.8	5.63	0	0.003	2.03	1.856	0.16	0.3	0.12	0.08	12.5	3.9	0.05	0.05	0.162	0.789	0	0

Images show example transient stability models and parameters

Example: 150 Bus Network for GMD Analysis


This is a synthetic power system model that does NOT represent the actual grid. It is intended for algorithm testing and education use. It contains no CEI information.

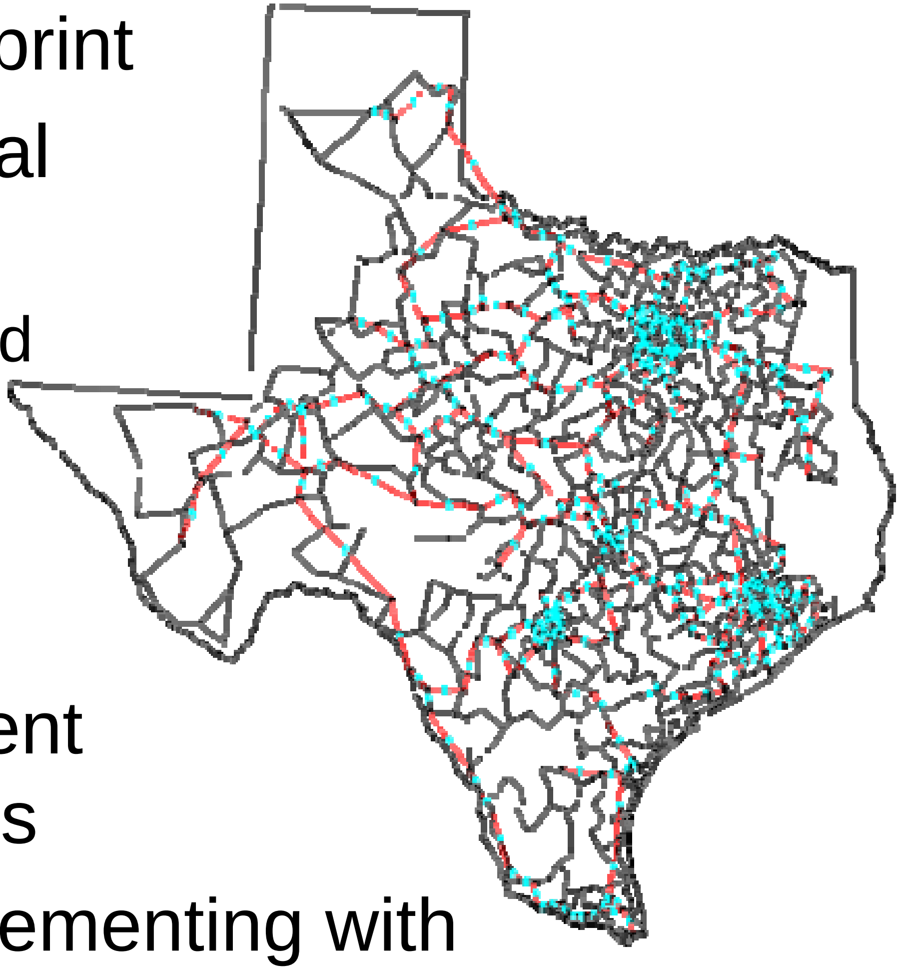


This is a synthetic power system model that does NOT represent the actual grid. It is intended for algorithm testing and education use. It contains no CEI information.

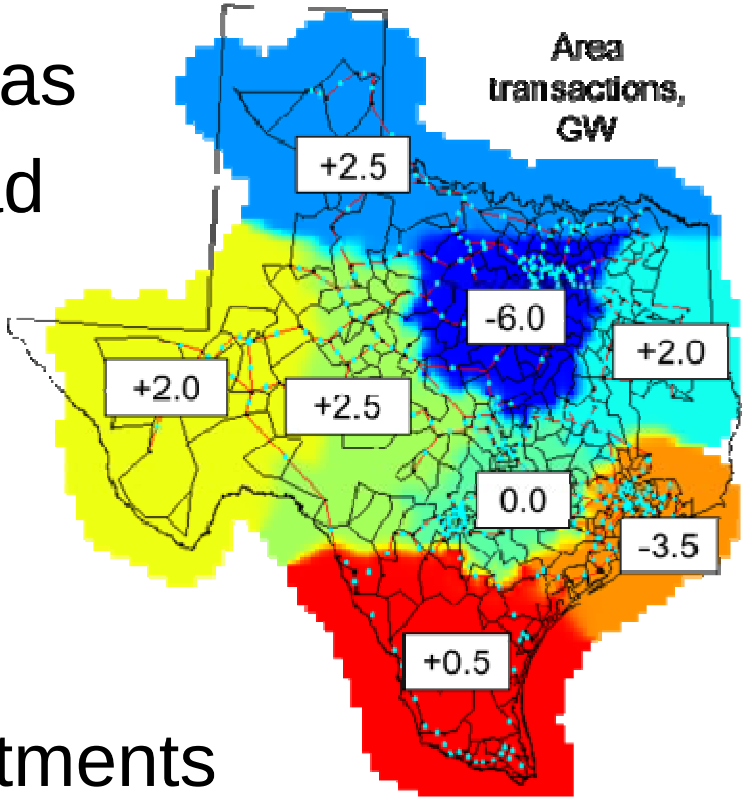
Images show a synthetic 150 bus model placed geographically in Tennessee; bottom image shows response to an assumed GMD.

1500 Substation, 2100 Bus Texas Example

- Texas geographic footprint
- No relationship to actual transmission grid
  - Nominal 345/115 kV grid
- 1500 substations, 2092 buses, 282 gens, 2857 branches
- Automatic line placement takes about 70 seconds
- Currently we are supplementing with manual adjustment for voltage control



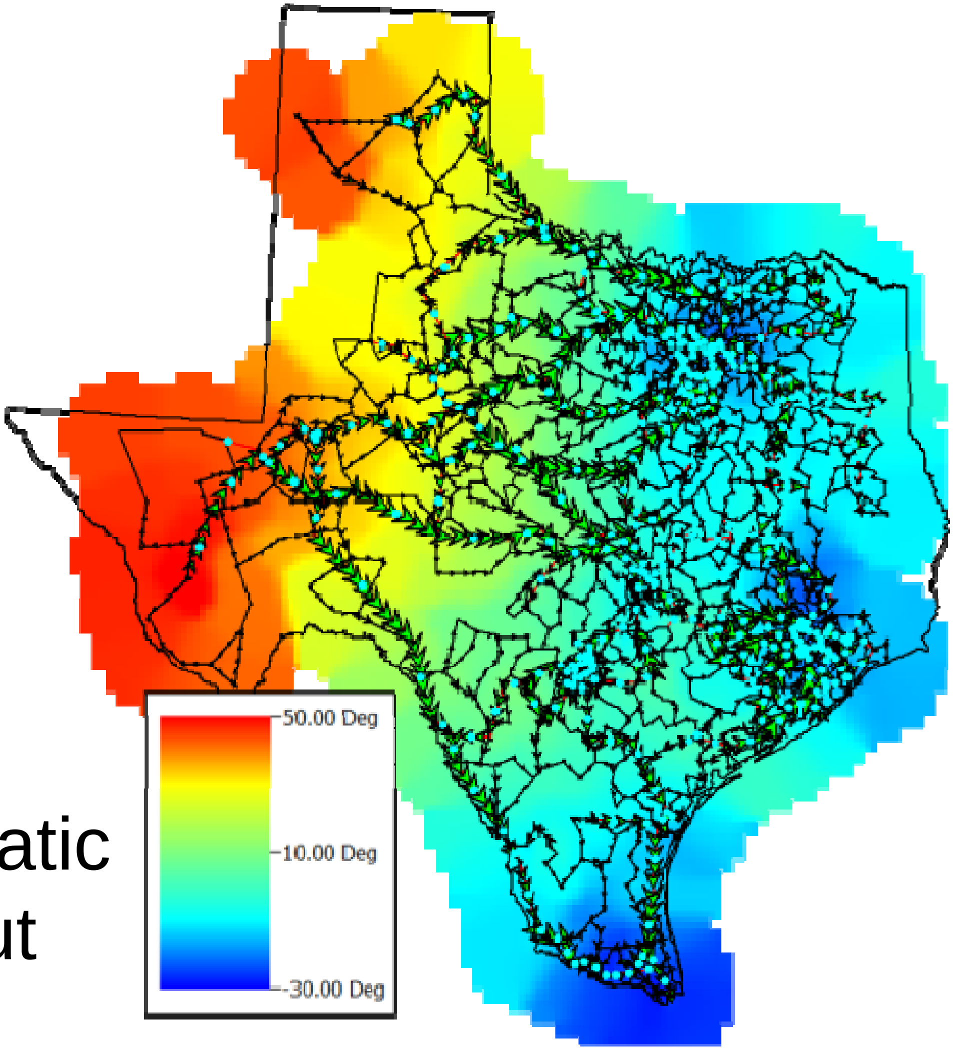
Example Case: Initial Generation Dispatch



- System divided into 8 areas
- Two areas have more load than generation capacity
- Transactions set up from other areas
- Generators dispatched proportionally to meet load + transaction commitments
- This is done before lines are placed, so that the algorithm’s dc power flow reflects realistic generation dispatch

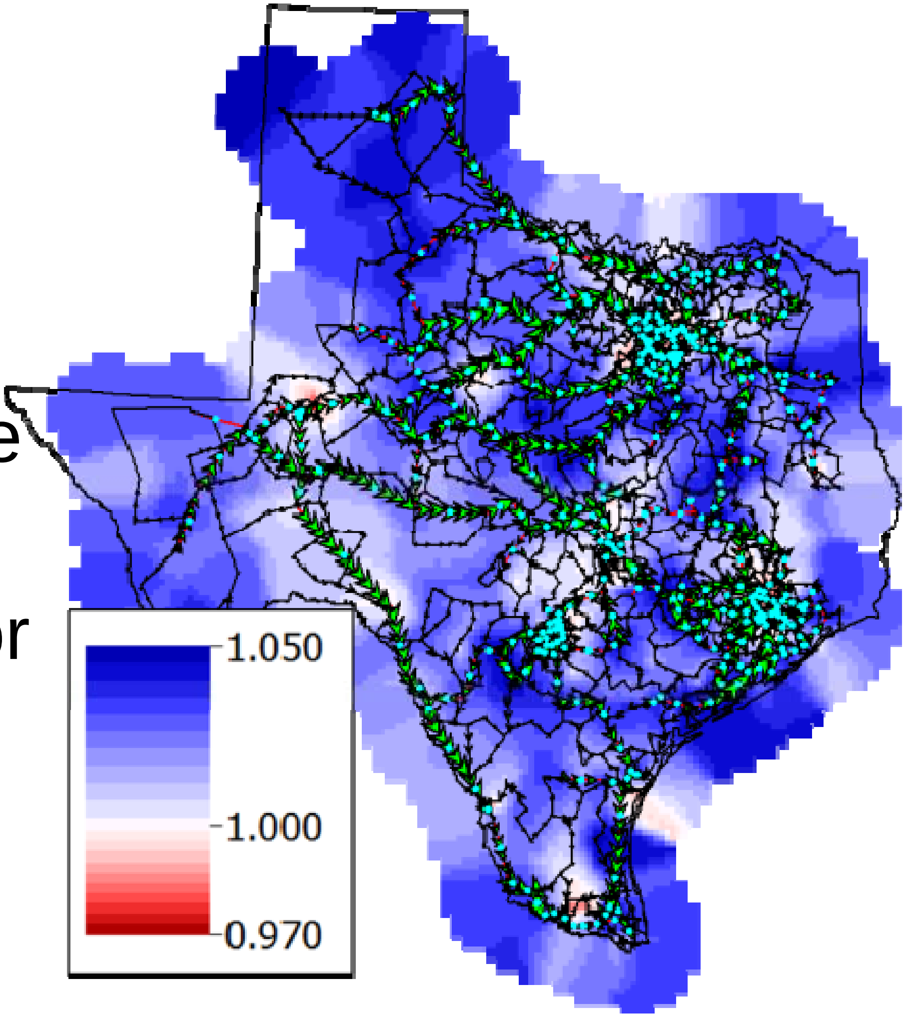
Example Case: Voltage Phase Angle Contour

- Gradual voltage angle gradient
- All branches less than 90% loaded
- Average branch is 28% loaded, matching real cases
- These properties are direct result of automatic line placement without manual intervention

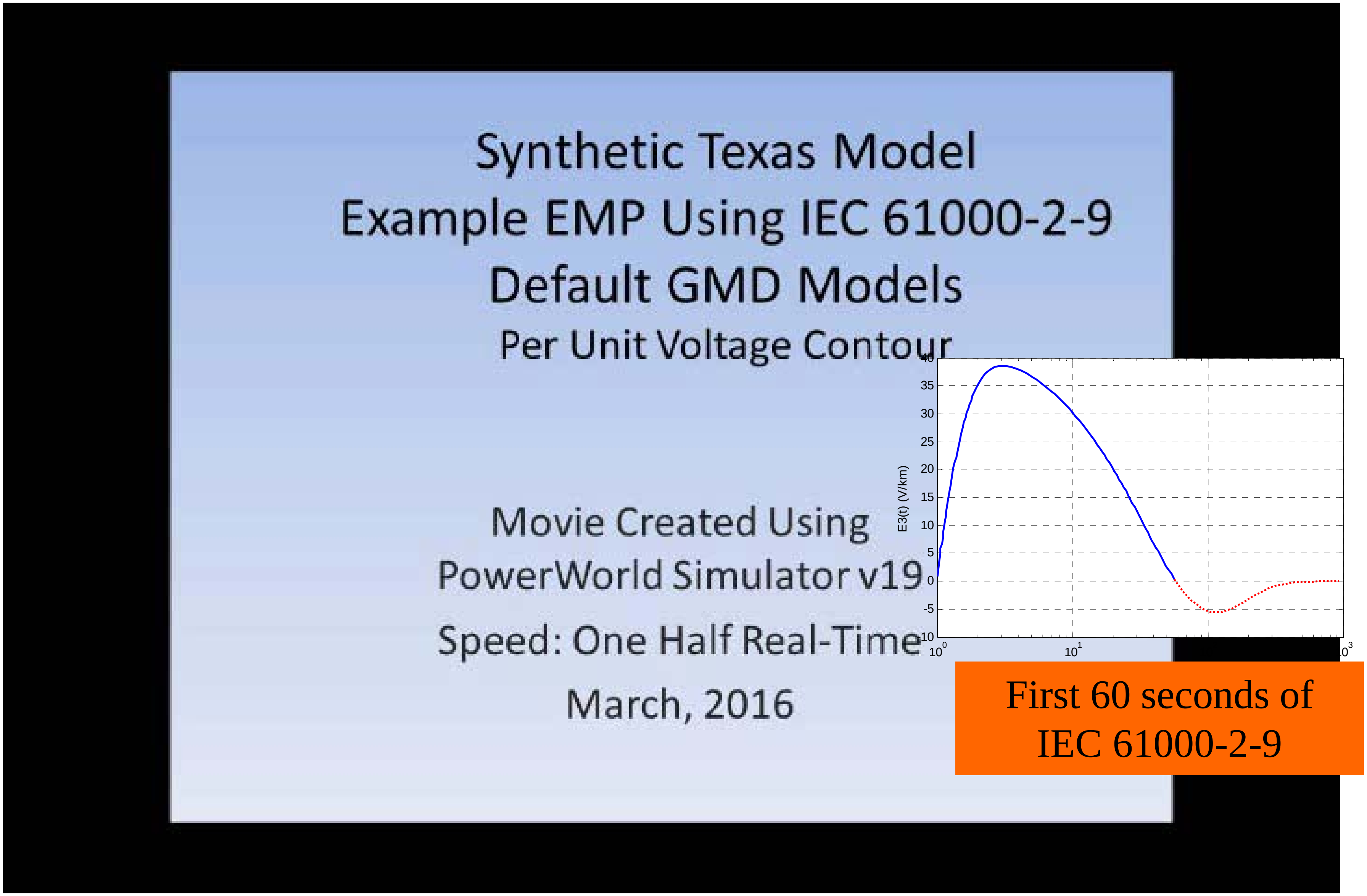


Example Case: Voltage Control

- All voltages within 0.97-1.05 pu in base case
- After line placement algorithm voltages were within 0.9 to 1.1 pu
- Adjustment of generator set points and insertion of 33 shunt capacitor banks in urban areas



Simulating High Impact, Low Frequency Events: Results can be Exchanged!



Synthetic Texas Model

Example EMP Using IEC 61000-2-9

Default GMD Models

Per Unit Voltage Contour

Movie Created Using

PowerWorld Simulator v19

Speed: One Half Real-Time

March, 2016

First 60 seconds of IEC 61000-2-9

Synthetic Model Validation

- Key to this research is to demonstrate synthetic models have similar properties of actual grids
- Synthetic models are **not** meant to represent the actual grid, so direct comparison is not appropriate
- Useful metrics are
  - Topological properties, which we meet by design
  - Individual model parameters, which we meet by design
  - Solution algorithm properties, such as power flow convergence
  - Solution results, such as LMPs, amount of congestion, transient stability damping, etc.

Driving Innovation!

- Goal is to publicly release synthetic models of various sizes and complexities
  - Algorithm results from synthetic models can be published without restriction; algorithms can be used confidentially on real models
  - Fully public, anyone can make derivative models; some models will be standardized for comparisons purposes
- Large-scale models can be used to compare software packages
  - Customers and researchers can compare results
  - Visualization research not hindered by confidentiality

Thank You!

Questions?

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