CHANGING WHAT'S POSSIBLE

Generating Realistic Information for the Development of Distribution And Transmission Algorithms

GRID DATA Program Overview

Tim Heidel

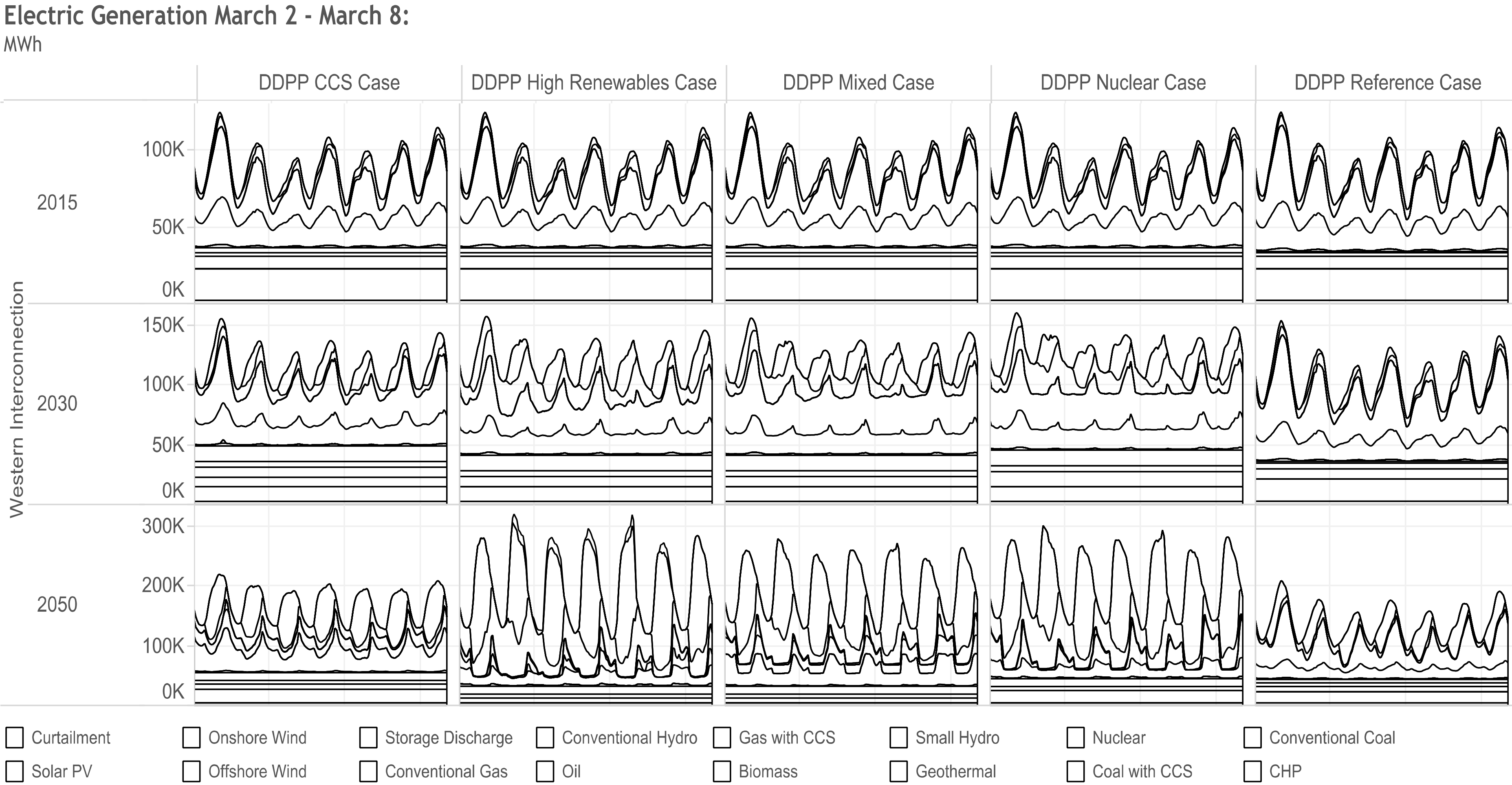
Advanced Research Projects Agency – Energy (ARPA-E)

U.S. Department of Energy

GRID DATA Annual Program Review
San Diego, CA - January 26-27, 2017

U.S. DEPARTMENT OF ENERGY

DDPP: Electricity Dispatch (Example Week)



Williams, J.H., B. Haley, F. Kahrl, J. Moore, A.D. Jones, M.S. Torn, H. McJeon (2014). *Pathways to deep decarbonization in the United States*. The U.S. report of the Deep Decarbonization Pathways Project of the Sustainable Development Solutions Network and the Institute for Sustainable Development and International Relations. Revision with technical supplement, Nov 16, 2015.

Emerging grid challenges

- Increasing wind and solar generation
- Electrification / Changing demand profiles
- Decentralization of generation
- Aging infrastructure
- Increasing natural gas generation
- Cybersecurity threats

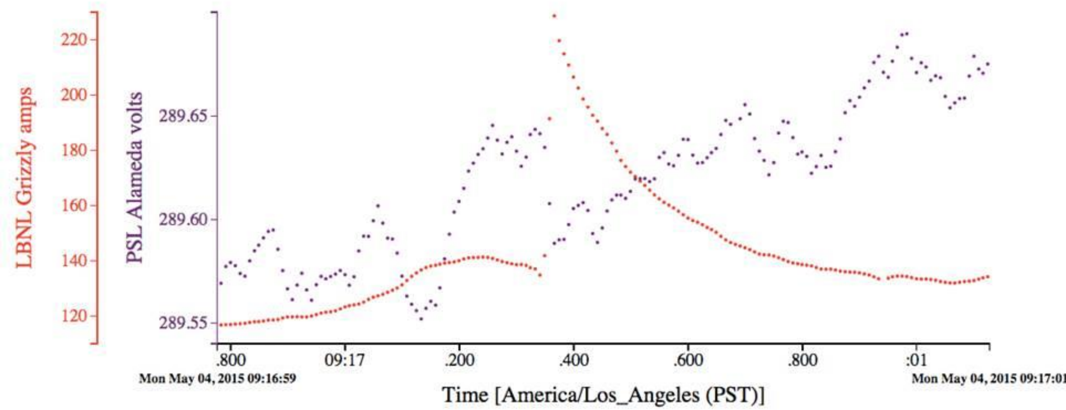
- Key research opportunities to address new challenges:
  1. Understanding: Improved system state awareness & visibility
  2. Controls: Power flow control & dispatchable demand
  3. Optimization: Faster, more robust, scalable algorithms

Understanding: ***Improved system state awareness & visibility***

Micro-synchrophasors for distribution systems

PI: Dr. Alexandra von Meier, California Institute for Energy and Environment

- Project objectives:
  - Develop, test, and certify a micro-PMU capable of measuring voltage phase angle to within < 0.005°
  - Develop open-source software (Quasar) for archiving, visualizing, and analyzing micro-PMU data
  - Study the value of voltage angle as a state variable in distribution systems
  - Explore applications of μPMU data for distribution systems to improve operations, increase reliability, and enable integration of renewables and other distributed resources
  - Evaluate the requirements for μPMU data to support specific diagnostic and control applications

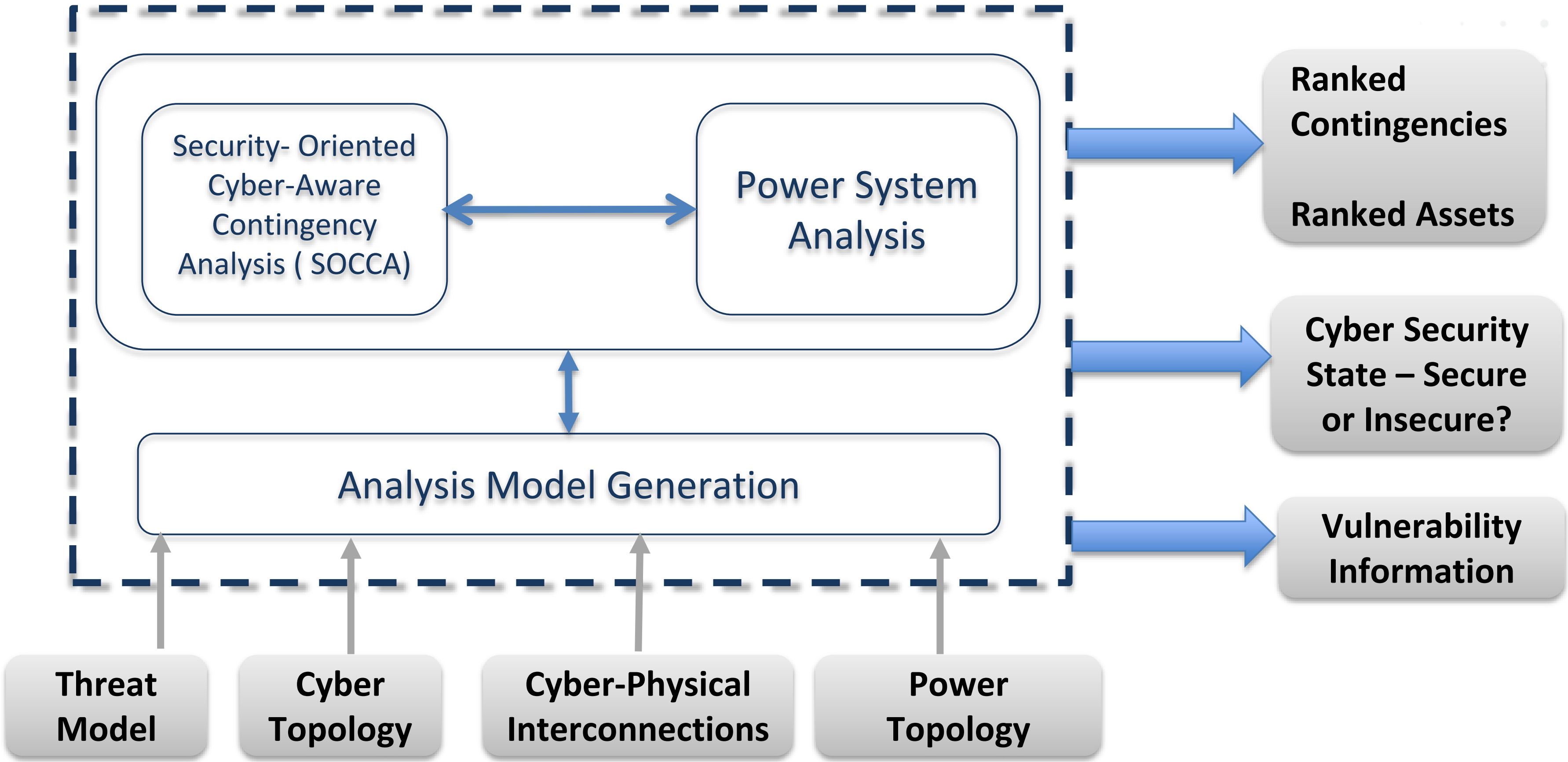


A small current surge at Lawrence Berkeley National Lab lowers the voltage at PSL, 40 km away. Precise time synchronization and ultrahigh resolution is required to observe these kinds of relationships in distribution systems.

Cyber-physical security assessment

PI: Prof. Pete Sauer, University of Illinois Urbana-Champaign

- Developing a tool to co-utilize information from cyber and power networks to determine the state of the cyber-physical system and provide a scalable approach to detecting and quantifying reliability threats due to cyber vulnerabilities

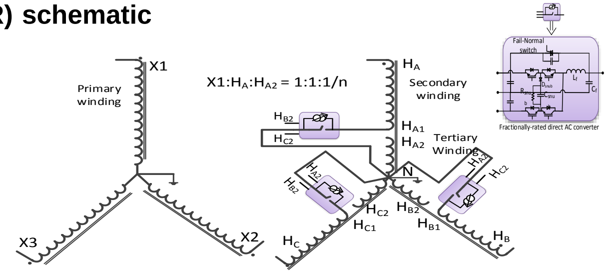


Controls:
Power flow control
& dispatchable demand

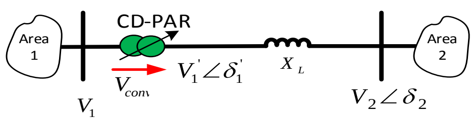
Compact dynamic phase angle regulators

PI: Prof. Deepak Divan, Georgia Tech & Varentec

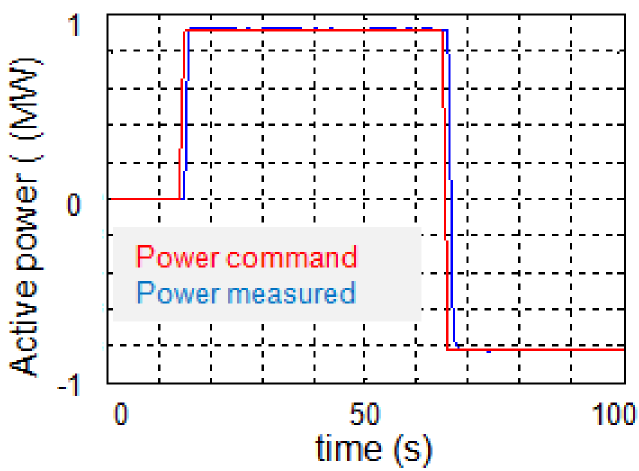
Grounded compact dynamic phase angle regulator (G-CDPAR) schematic



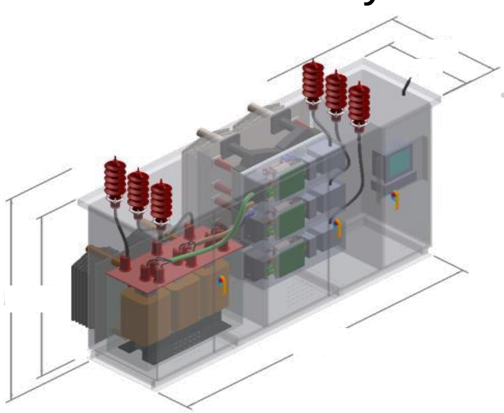
Principle of operation



Closed loop control with power command dispatched from remote control station.



- Fractionally-rated converters (AC switches/ LC filters) connected to transformer
- ‘Fail-normal’ bypass switch preserves system reliability
- 3-phase CD-PAR operation verified at 13 kV 1 MVA
- Target: $20-30/kVA of power controlled
- Dynamic and steady-state impact of CD-PAR at both distribution and transmission systems simulated by research team



Georgia Tech

varentec

EPRI

SPX

SOUTHERN COMPANY

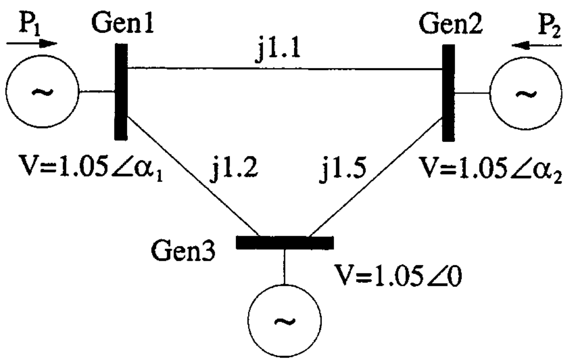
SMART WIRES
REIMAGINE THE GRID

50uH (<150 lbs) Prototype
Distributed Series Reactor

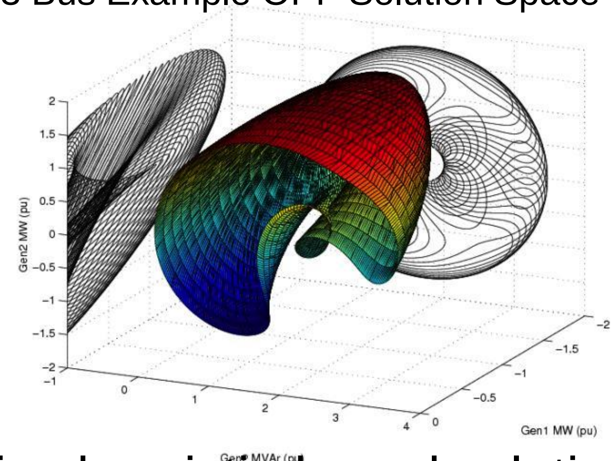
Optimization:
Faster, more robust, scalable algorithms

Optimizing Grid Power Flows is Hard

- Optimizing grid power flows (subject to the physical constraints of generators, transmission lines, etc.) is a difficult, non-convex optimization problem



3 Bus Example OPF Solution Space



- Simplifying assumptions and/or iterative heuristic-based solution methods required to achieve reasonable solutions within time constraints
- No commercial tool can fully utilize all network control opportunities (generators, transformers, power flow controllers, voltage setpoints, etc.)
- OPF is rarely used in distribution system operations. Existing algorithms unlikely to scale to distribution system scale (1,000,000+ nodes)

- I.A. Hiskens and R.J. Davy, "Exploring the power flow solution space boundary", IEEE Transactions on Power Systems, Vol. 16, No. 3, August 2001, pp. 389-395.

Recent advances could offer improved OPF

- Continued reductions in advanced computing costs
- Rapid optimization solver improvements (especially MIP)
- Reevaluation of alternative problem formulations (IV Formulation)
- Fast, accurate convex relaxations for OPF (SDP/QC/SOCP relaxations)
- Distributed approaches to OPF (ADMM)

New OPF methods struggling to gain traction

- Existing public R&D datasets are not adequate
  - There are too few of them
  - They are too small
  - They are incomplete
  - They are too easy
  - They are a not representative of real systems

ARPA-E "GRID DATA" Program

- No rigorous way to compare existing tools to new methods
  - Some new algorithms poorly handle complex, real-world constraints and requirements

Challenges with requiring real datasets

- Realistic, large-scale datasets are extremely valuable but also difficult, time consuming and expensive to collect, prepare, and use
  - Every team must negotiate unique data agreement
  - Base cases from ISO/utilities usually do not converge (substantial cleaning always required)

- Data typically cannot be published in detail in any form
  - Very difficult to independently verify/replicate results
  - Results may reflect quality of data more than quality of algorithms

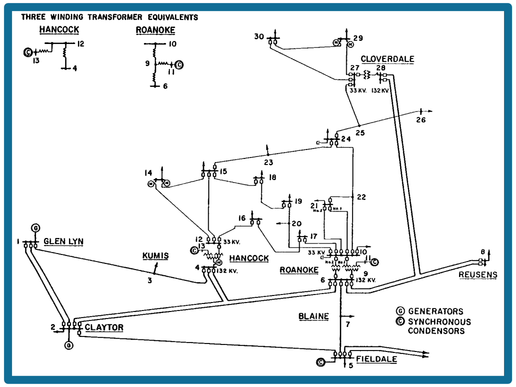
- ISOs/utilities have limited bandwidth to devote to R&D
  - Very few teams can put together credible project plans up front
  - High barrier to entry for those not already in power systems field

Public Benchmark Power System Datasets

Public OPF test systems are drawn from:

- IEEE Power Flow, Dynamic and Reliability Test Cases, MATPOWER, Edinburgh, EIRGrid, Other Publication Test Cases

There are fewer than 50 widely available public datasets.



IEEE 30 bus.

- Existing datasets are not adequate
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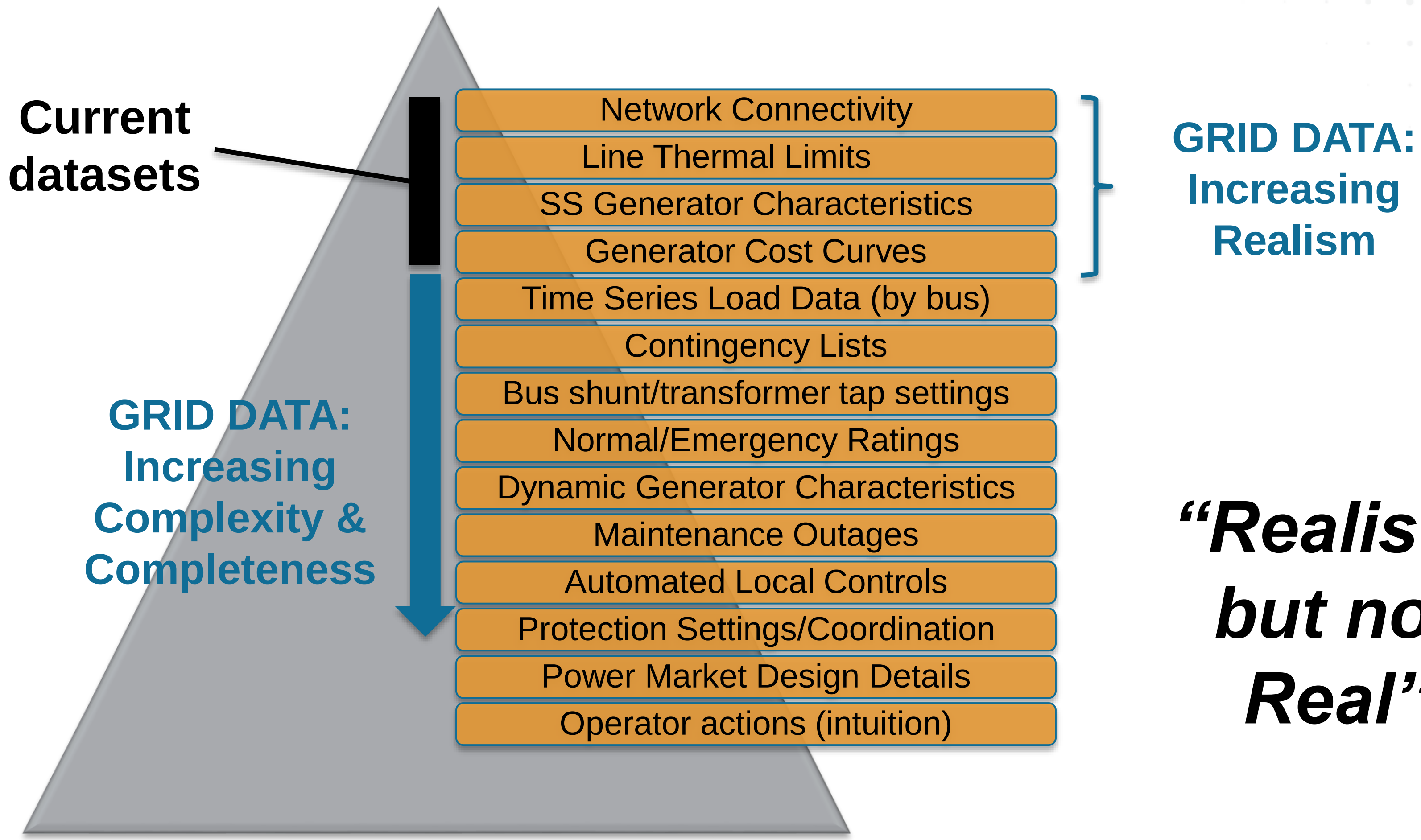
Not representative of real systems (Examples)

- Extremely large (typically unobserved) voltage drops
- Low base voltages and an overabundance of voltage control capacity
- Lines with non-physical negative resistances (due to undocumented network reductions).
- Lines with non-zero MW thermal emergency ratings, zero MW normal ratings.
- All generators of each type have identical characteristics (and cost curves).
- Identical subnetworks are repeated multiple times.
- Omitted: Lists of contingencies, emergency (short term) equipment ratings, protection system details, generator ramp rates and real and reactive capability curves, transformer tap settings, capacitor bank locations and settings, phase shifting transformer characteristics, energy storage capacity, line switching capabilities, flexible demand, etc.

GRID DATA Program Objective

Accelerating the development, evaluation, and adoption of new grid optimization algorithms will require more realistic, detailed public datasets.



"Realistic but not Real"

Dataset creation pathways

Real Data

- Start with real data, then anonymize, perturb topologies and change sensitive infrastructure asset data as necessary
- **Risks**:
  - Requires extremely close collaboration with ISOs such that infrastructure is not reconstructable and can be publically released
  - Datasets may no longer well represent real data
  - Real data is often messy, incomplete

Synthetic Data

- Generate via expert input, geographic/road data and data mining
- Generate new random graph methods for transmission networks
- Devise statistical metrics (moments of capacity distributions, degree distributions of networks); validate against real data
- **Risks**:
  - Validation metrics may be incomplete or misleading (Leading to lack of realism)

Open-access, large, realistic, validated datasets

New Model/Dataset Repositories Needed

- Enhance research repeatability (and transparency) by enabling the collaborative maintenance and version control of models

- Researchers need to be able to easily contribute and share new models with the community

- Open source software development community has enabled highly productive, widely distributed, technical collaboration involving thousands of individuals

GRID DATA Program

Generating Realistic Information for the Development of Distribution And Transmission Algorithms

Goals

Development of large-scale, realistic, validated, and open-access electric power system network models with the detail required for successful development and testing of new power system optimization and control algorithms.

Duration	2016-2018
Projects	7
Total Investment	$11 Million

Project Categories

- Transmission, Distribution, and Hybrid Power System Models & Scenarios
  - Models derived from anonymized/obfuscated data provided by industry partners
  - Synthetic models (matching statistical characteristics of real world systems)

- Power System Model Repositories
  - Enabling the collaborative design, use, annotation, and archiving of R&D models

GRID DATA project portfolio

T Transmission Models
H Hybrid Models
D Distribution Models

	Lead Organization	Principle Investigator	Project Partners	
Model/Dataset Development	University of Michigan	*Prof. P. Van Hentenryck*	California Institute of Technology, Columbia University, Los Alamos National Lab, RTE France	T
	Wisconsin University of Wisconsin–Madison	*Prof. C. DeMarco*	Argonne National Laboratory, ComEd, GE/Alstom Grid, GAMS	T
	Illinois University of Illinois at Urbana-Champaign	*Prof. T. Overbye*	Cornell University, Arizona State University, Virginia Commonwealth University	T
	Pacific Northwest National Laboratory	*Dr. H. Huang*	National Rural Electric Cooperative Association, Alstom Grid, PJM, Avista, and CAISO	H
	NREL National Renewable Energy Laboratory	*Dr. B. Hodge & Dr. B. Palmintier*	MIT-Comillas-IIT and GE/Alstom Grid	D
Repositories	GridBright	*Dr. A. Vojdani*	Utility Integration Solutions, LLC (UISOL, a GE Company)	
	Pacific Northwest National Laboratory	*Dr. M. Rice*	National Rural Electric Cooperative Association	

Power System Network Model Requirements

- Teams may choose to address any specific OPF application(s)
- Any method(s) may be used to create test systems (using real-world data or purely synthetic approaches)
- Teams may choose to address (i) transmission/bulk power systems, (ii) distribution systems, or (iii) hybrid transmission and distribution systems.

Transmission	At least one small network model having between 50 and 250 electrical buses required and at least one large network model having > 5,000 buses. (Larger test systems may not consist of repeated duplicates of smaller systems.)
Distribution	At least one model with at least 3 independent feeders originating at one or more substations, corresponding to a minimum of at least 5,000 individual customers.

- Required and optional model details were specified in the FOA
- Detailed plan for validation with technical success/fail criteria required
- Models must be publicly releasable and must not contain CEII data

Scenario Creation Requirements

- Scenario sets must be designed with temporal resolutions and time-coupling suitable for solving one or more specific OPF problems
- Any method(s) may be used to create power system scenarios (using real-world data or purely synthetic approaches)
- Teams must generate at least a full year of time-coupled physically feasible scenarios with at least hourly granularity. (Teams are strongly encouraged to use the shortest feasible time step between scenarios (5 minutes, 15 minutes, etc.)).
- Scenarios must represent a range of difficulty to OPF optimization algorithms. Teams are also encouraged to develop infeasible scenarios (to test the ability for OPF algorithms to identify infeasibility quickly).
- Required and optional scenario details were described in the FOA
- Teams must have a detailed plan for validation with technical success/fail criteria to ensure scenarios are sufficiently representative of a range of real-world power system operating conditions

Repository Creation Requirements

- The repository must be completely open (including international access), giving researchers the ability to upload modified versions of existing models and designate relationships between different models (i.e. version control) as well as provide annotation and/or comments on specific models (similar to, for example, GitHub)
- The repository should be able to accommodate different kinds of power system models (not just ones suitable for OPF control and optimization)
- The repository should have the ability to scale the repository to archive an arbitrary number of power system models
- Teams have proposed a self-funding mechanism with potential to extend well beyond ARPA-E's development funding
- Teams are required to establish a set of standards for models and a clear self-governance model for the repositories
- The teams must design a plan for active curation of power system models in the repositories

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ARPA-E “GRID DATA” Program

Launched: Early 2016

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  - Some new algorithms poorly handle complex, real-world constraints and requirements

Competition success stories

Longitudinal Prize of 1714

Found 10 balloons across U.S. in under 9 hours

CYBER GRAND_CHALLENGE

Automated software vulnerability identification and protection

$1M Prize
Winner 10.6% improvement

GRID OPTIMIZATION (GO) COMPETITION

Goals

Accelerate the development and comprehensive evaluation of new solution methods for grid optimization. Provide a platform for the identification of transformational and disruptive methods for solving power system optimization problems.

Competition Design Requirements

1. Realistic, challenging benchmarking test systems

2. Detailed, accessible problem definition
   - Sufficiently complex to be valuable but accessible to non-domain experts
   - Clear objective(s) and desired solution characteristics
   - Consistent, clear modeling assumptions (consistent with industry needs)
   - Transparent, quantitative scoring criteria

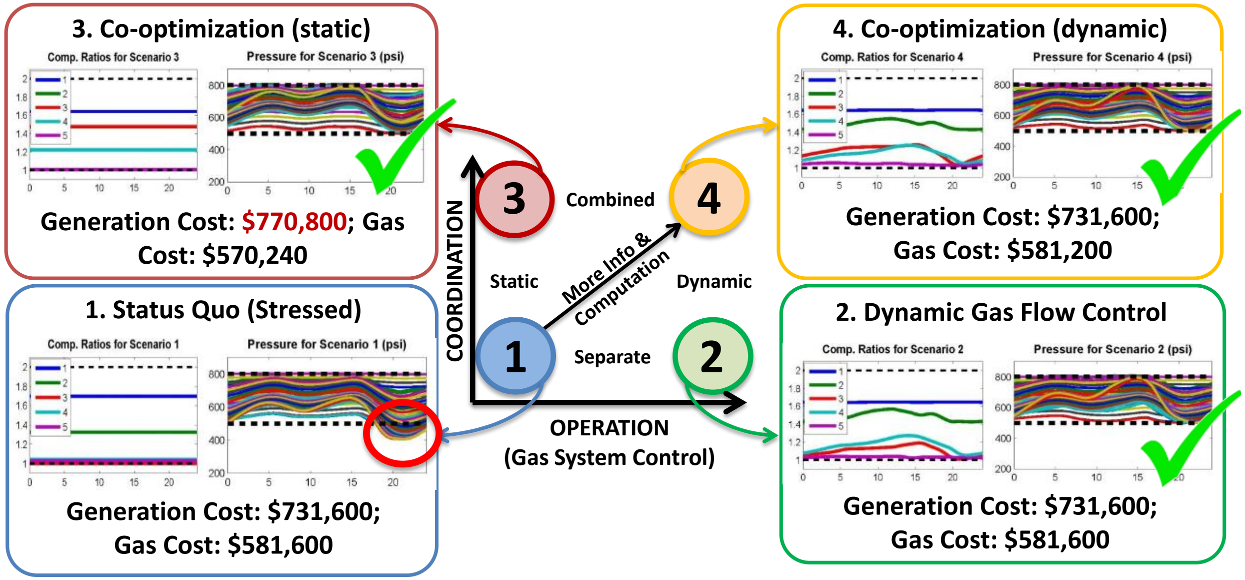
3. Fair solution method evaluation platform or method
   - Automated evaluation and scoring using a consistent computational platform
   - Separation of training and competition datasets
   - Public leaderboard to promote active participation

Gas-electric co-optimization (GECO)

PI: Dr. Aleksandr Rudkevich, Newton Energy Group LLC

Project objectives:

- Develop novel mathematical modeling and optimization method to control operation of natural gas pipelines
- Design market mechanisms for coordinated operations of natural gas and electric networks
- Develop software to align gas and electric markets



Metric	State of the art	Proposed
Pipeline control logic	*Steady state*	*Dynamic*
Objective function	*Minimize cost of compression*	*Minimize cost of gas supply*
Gas price formation frequency	*Daily, 5 days per week, not aligned with electric prices*	*24/7, aligned with electric prices*

NEWTON ENERGY GROUP

Los Alamos NATIONAL LABORATORY EST. 1943

POLARIS PTIMIZATION

KINDER MORGAN

AIMMS

BOSTON UNIVERSITY

pjm

Meeting Objectives

- Reinforce and refine GRID DATA project objectives
- Assess and celebrate technical progress thus far
- Generate critical feedback on approaches and applications
- Explore partnership opportunities (within and beyond the program)
- Brainstorm strategies for maximizing GRID DATA impact
- Program Director transition planning

Key Questions

- Will the proposed datasets have sufficient fidelity to accelerate grid optimization algorithm development and evaluation?
- What are strongest ways to validate the realism of new datasets?
- Should validation procedures/metrics be leveraged across teams?
- How can we increase program visibility (both to build dataset awareness and to establish this domain as an area for important future research)?
- What features are highest priority for the GRID DATA repositories?
- Is the GRID DATA program on track to achieve its objectives?

Day 1 Agenda

Start Time	Institution	Project Title	Presenters
		DAY 1	
8:00	**ARPA-E**	**Welcome and Introductions**	**McGrath**
8:15	**ARPA-E**	**GRID DATA Program Update**	**Heidel**
8:45	Guest Speaker #1	Realistic Modeling For SC-ACOPF	Panciatici
		GRID DATA Model Development	
9:05	Wisconsin (GRID DATA)	EPIGRIDS: Electric Power Infrastructure & Grid Representation in Interoperable Data Set	DeMarco
9:35	Michigan (GRID DATA)	High Fidelity, Year Long Power Network Data Sets for Replicable Power System Research	Van Hentenryck
10:05		**BREAK**	
10:35	UIUC (GRID DATA)	Synthetic Data for Power Grid R&D	Overbye
11:05	PNNL (GRID DATA)	Sustainable Data Evolution Technology (SDET) for Power Grid Optimization	Diao
11:35	NREL (GRID DATA)	Smart-DS: Synthetic Models for Advanced, Realistic Testing: Distribution systems and Scenarios	Hodge
12:05	Discussion		
12:30		**LUNCH**	
13:30	Guest Speaker #2		Lin
13:50	Guest Speaker #3	Rapid Attack Detection, Isolation and Characterization Systems	VanPutte
		GRID DATA BREAKOUT SESSIONS	
14:15		**BREAKOUT SESSION #1:**	
15:30		**BREAK**	
16:00		**BREAKOUT SESSION #1 Reports**	
16:30	Guest Speaker #4	A Vendor's Perspective on the GRID DATA Efforts	Frame
16:50	GridBright (GRID DATA)	Repository Demo	Nielsen
17:10	PNNL (DR POWER)	Repository Demo	Kuchar
17:30		**POSTER SESSION**	
** Poster Session Runs 17:30-19:00			

CHANGING WHAT'S POSSIBLE

Day 2 Agenda

8:00	**ARPA-E**	**Welcome and Recap**	**Heidel**
		GRID DATA Repository Development	
8:15	PNNL (GRID DATA)	Data Repository for Power system Open models With Evolving Resources (DR POWER)	Kuchar
8:45	GridBright (GRID DATA)	A Standards-Based Intelligent Repository for Collaborative Grid Model Management	Vojdani
9:15	Discussion		
9:45		**BREAK**	
		Related OPEN FOA 2012 Projects	
10:15	Avista/kaedego (OPEN 2012)	Cyber-Physical Modeling and Analysis for a Smart and Resilient Grid	Davis
10:40	CIEE (OPEN 2012)	Micro-Synchrophasors for Distribution Systems	Von Meier
		OPEN FOA 2015 Projects	
11:05	Newton Energy Group (OPEN 2015)	Coordinated Operation of Electric And Natural Gas Supply Networks: Optimization Processes And Market Design	Rudkevich
11:30	Discussion		
12:00	**Final Discussion**	**Program Director Wrap-up**	**Heidel**
12:30		**LUNCH**	

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