CHANGING WHAT'S POSSIBLE

Optimal Power Flow Competition Design Considerations

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Increasing Market and Planning Efficiency through Improved Software
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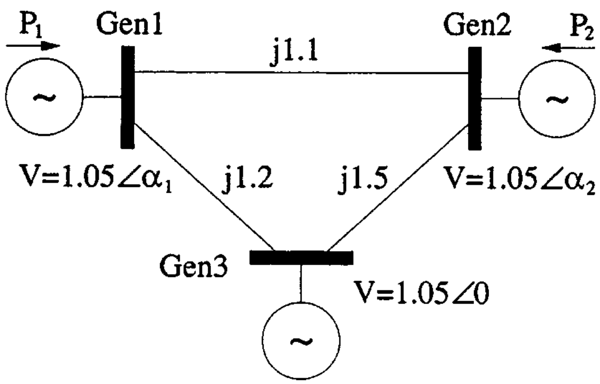
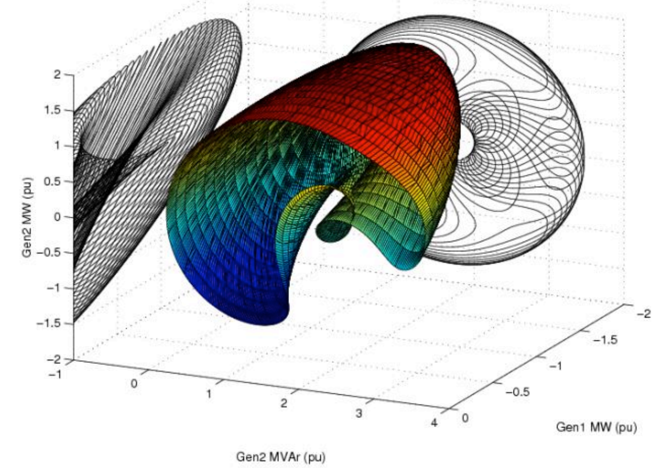
Optimizing Grid Power Flows is Hard

- 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

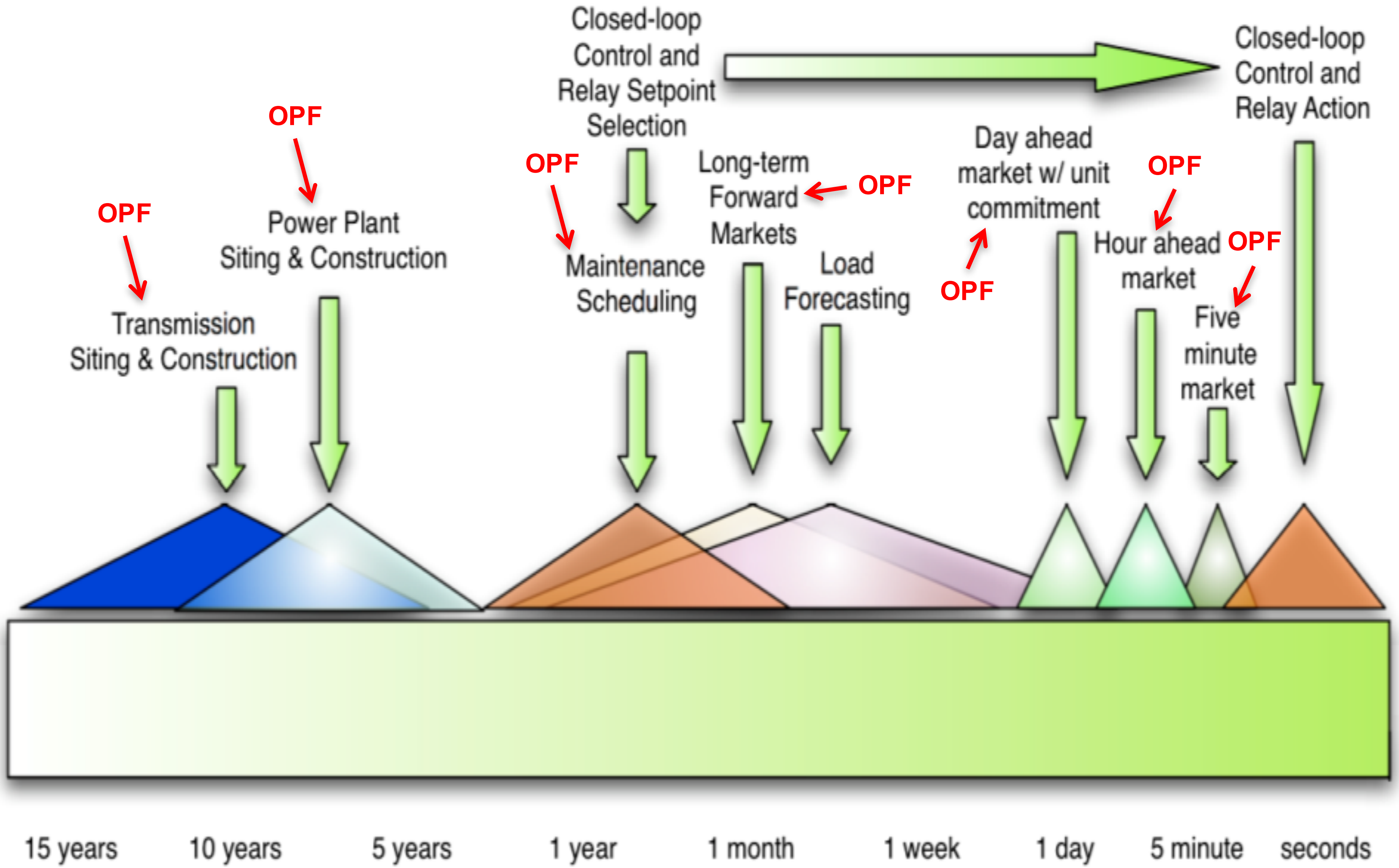


- Simplifying assumptions and/or iterative heuristic-based solution methods are required to achieve reasonable solutions within time constraints.
- No commercial tool can fully utilize all network control opportunities (generators, transformers, power flow controllers, voltage set-points, etc.)
- Existing OPF tools do not guarantee a physical solution (feasibility of solution must be assessed separately).

- 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.

Electric grid operations depend on OPF

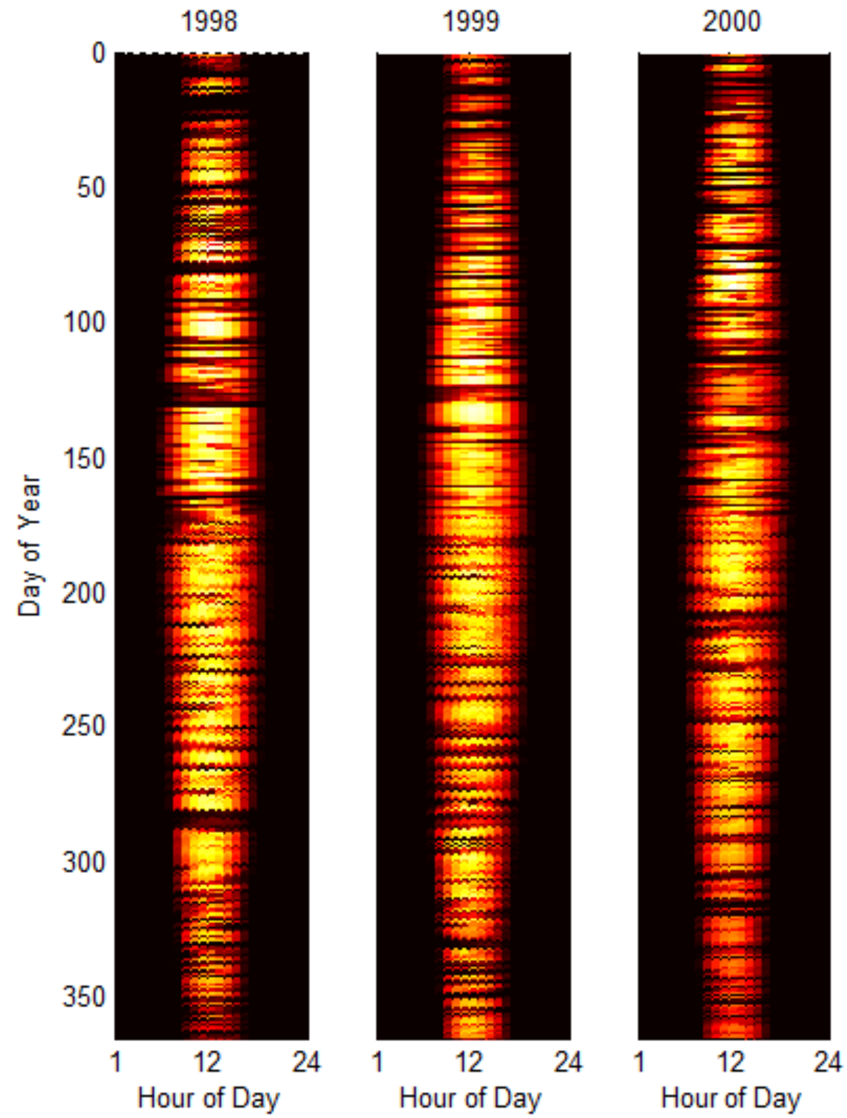
- **Fully leveraging power flow controllers and other emerging technologies will require new Optimal Power Flow (OPF) tools…**



Emerging Grid Challenges

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

All of these challenges require new tools for faster, better, more robust grid optimization.



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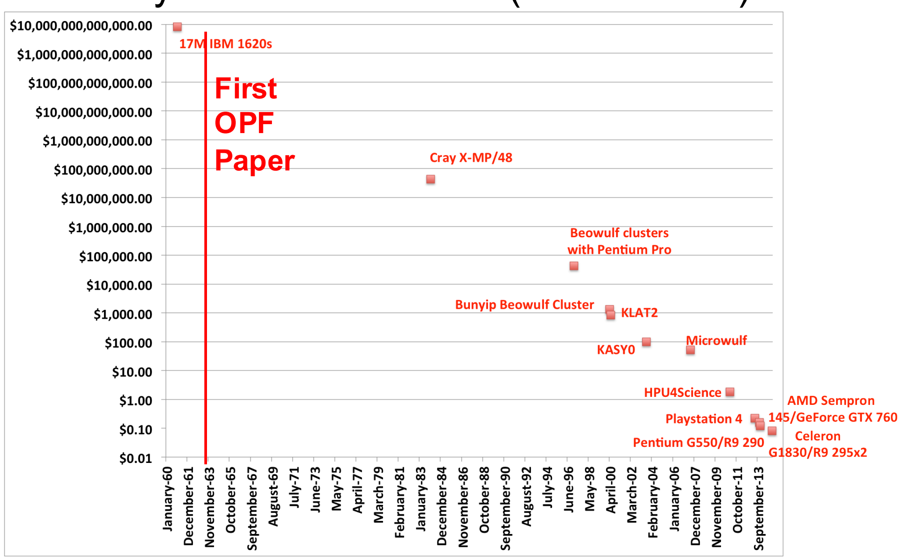
Recent advances could offer improved OPF

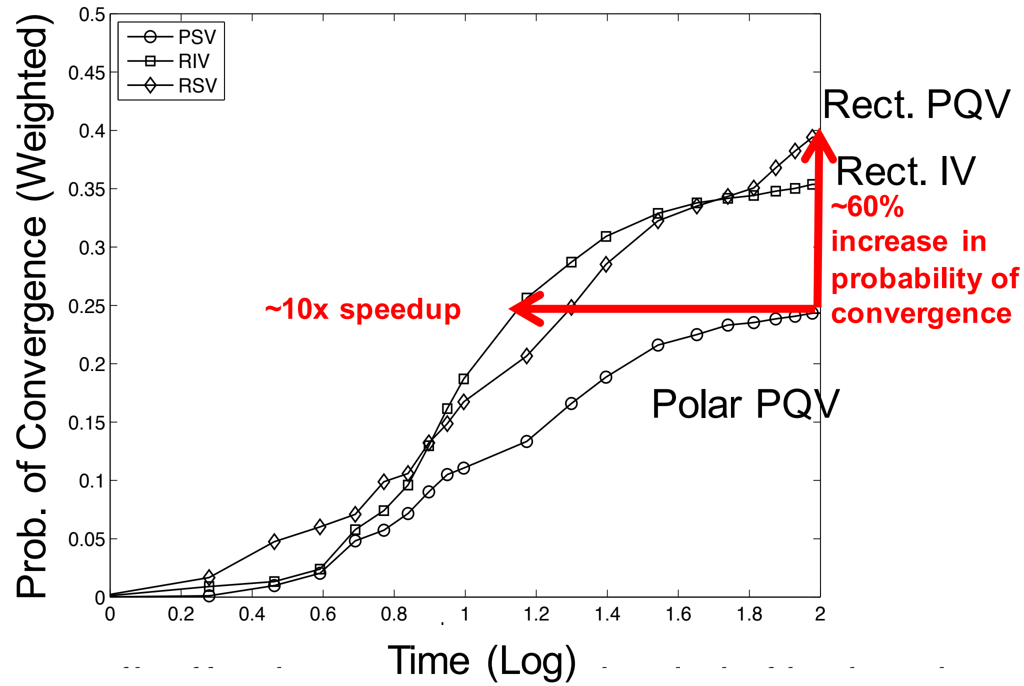
- Continued reductions in advanced computing costs
- Rapid optimization solver improvements (especially MIP)
- Reevaluation of alternative problem formulations (IV Formulation)
- Fast, accurate convex relaxations for OPF (SDP/QC/SOCP relaxations)
- Distributed approaches to OPF (ADMM)

System Cost/GFLOP (2015 dollars)



Cost has been reduced from $8.3 trillion/GFLOP in 1961 to 8 cents/GFLOP in 2015.

www.top500.org



FERC staff. Optimal Power flow and Formulation Papers 1-11, http://www.ferc.gov/industries/electric/indus-act/market-planning/opf-papers.asp#p1

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Benefits of Faster, More Robust OPF

- Improved economic efficiency
  - Reduced power generation costs
  - Reduced transmission losses
  - Deferred investments in transmission and generation
- Increased grid flexibility
  - Dynamic power routing (using power electronics-based devices)
  - Optimal transmission switching
  - Optimal utilization of energy storage
  - Demand side control
- Support for increasingly complex generation mix
  - Distributed generation
  - Variable, uncertain renewable generation
- Autonomous control (Fewer routine, manual operator decisions)

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
(Launched Early 2016)

- No rigorous way to compare existing tools to new methods
  - Large gap between idealized (simplified) problem formulations in research community and industry problems

Competition Success Stories

IEEE Forecasting Competition

Held in 2012 & 2014
40% reduction in RMSE

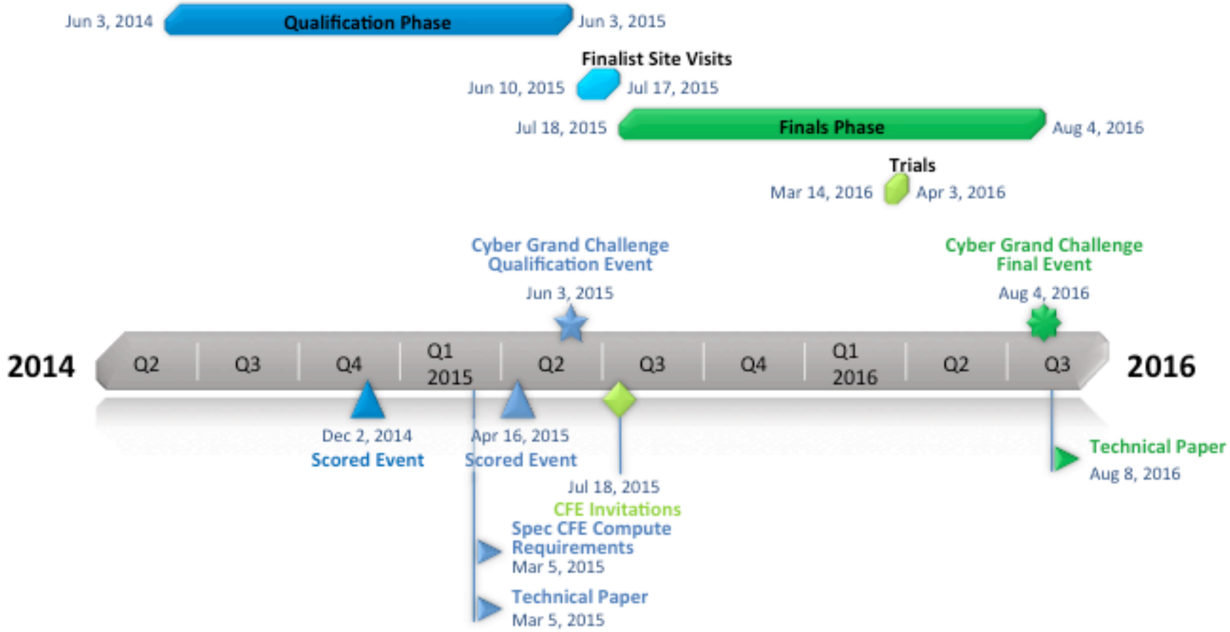
Found 10 balloons across
U.S. in under 9 hours

CYBER
GRAND_CHALLENGE

DARPA Cyber Grand Challenge:
Autonomous Cyber Defense Systems

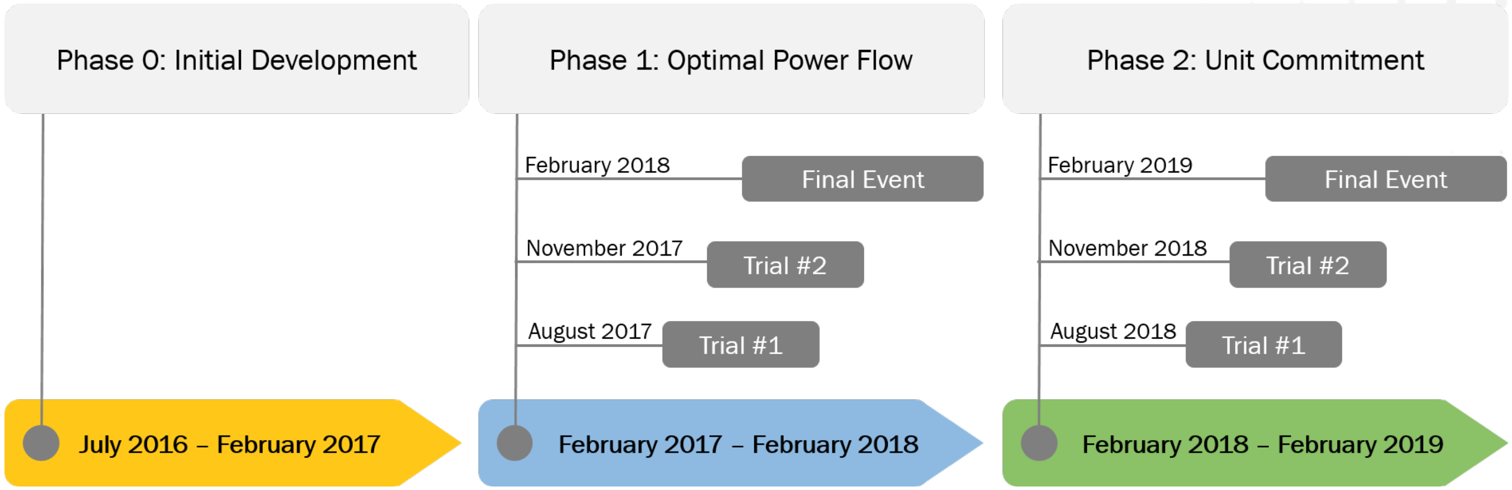
$1M Prize
Winner 10.6% improvement

DARPA Cyber Grand Challenge As a Model



- Competition to design automated tools for software cyber-security vulnerability identification and patching.
- Two competition phases: "Qualification Phase" and "Finals Phase."
- Two Qualification Phase Tracks:
  - Proposal Track: 7 teams selected/funded via solicitation @ $750k each.
  - Open Track: Unlimited number of teams, no DARPA funding during this phase.
- Finals Phase: 3 "Funded Track" teams and 4 "Open Track" teams @ $750k each.

Possible Competition Structure and Timeline



- Phase 0:
  - Competition website live with toy problems (existing datasets)
  - FOA released to fund Phase 1 “Proposal Track” teams (~X teams at $XXX each)
- Phase 1:
  - OPF problem relying on small, medium, and large GRID DATA models.
  - Two scored “trials” and the “Phase 1 Final Event”
  - Top ~X teams “win” $XXX for participation in Phase 2.
- Phase 2:
  - Unit Commitment problem (with AC power flow) relying on final GRID DATA models.
  - Grand Prize: $XXX, 2^{nd} Place: $YYY, 3^{rd} Place: $ZZZ

Algorithm Competition Requirements

1. Realistic, challenging benchmarking test systems
2. Detailed, accessible problem definition
   – Sufficiently complex to be industrially relevant and 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 of solution methods using a consistent, carefully instrumented computational platform
   – Separation of training and competition datasets
   – Public leaderboard to promote active participation

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	2016-2019
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	

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Support Team Introduction and Responsibilities

Key Competition Design Activities:

- Optimization problem selection
- Data set selection and preparation
- Competition platform design
  - Website
  - Back-end server and evaluation system
  - Hardware
- Design of evaluation procedure and scoring
- Identification and building/acquisition of required resources
  - Solvers, programming languages, forum
- Outreach & Communications

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Optimization Problem Selection

- OPF is used in a wide variety of specific applications. Competition problem could be too easy or too difficult to engage the right research community stakeholders.
- Problem selection criteria:
  - Industry relevance, specific and broad impact on applications
  - Research community relevance, exercise state-of-the-art solution methods
  - Reasonable learning curve for participants from adjacent disciplines
  - Dataset availability
- Potential problems
  - SCOPF + droop control
  - SCOPF + re-dispatch (Two stage problem with additional generation dispatch variables for each contingency)
  - SCOPF with discrete controls (transformer taps, switching capacitors, etc.)
  - Unit Commitment (with AC power flow constraints)
  - Stochastic SCOPF or UC with defined probabilistic scenarios

Optimization Problem: First Formulation

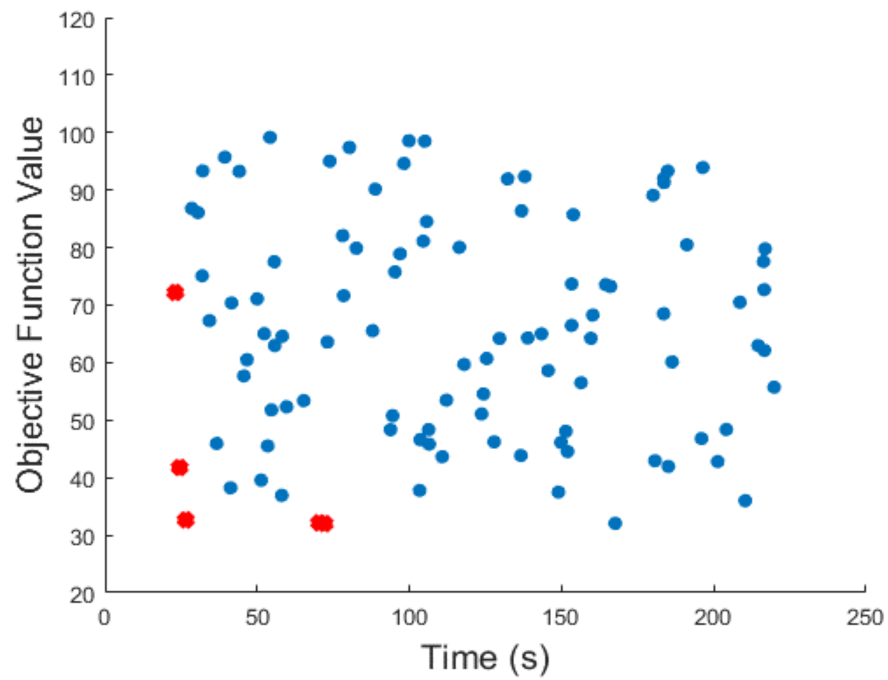
Competition Problem: Security constrained optimal power flow with droop control (with provided generator participation factors).

	Objective	Minimize total dispatch cost
Subject to	Base-case	power flow balance system limits
	Contingency cases	power flow balance system limits voltage set point droop control (participation factors provided in dataset)

Detailed problem formulation will be published at competition start, solutions will be verified through forward evaluation.

Scoring

- Goal is to evaluate quality of an algorithm while preventing gaming.
- Scoring targets and/or objective function construction must be aligned with industry priorities.
- Three main metrics
  - Objective value
  - Computation time
  - Constraint violations
- Automated evaluation and scoring ensures transparency and fairness.



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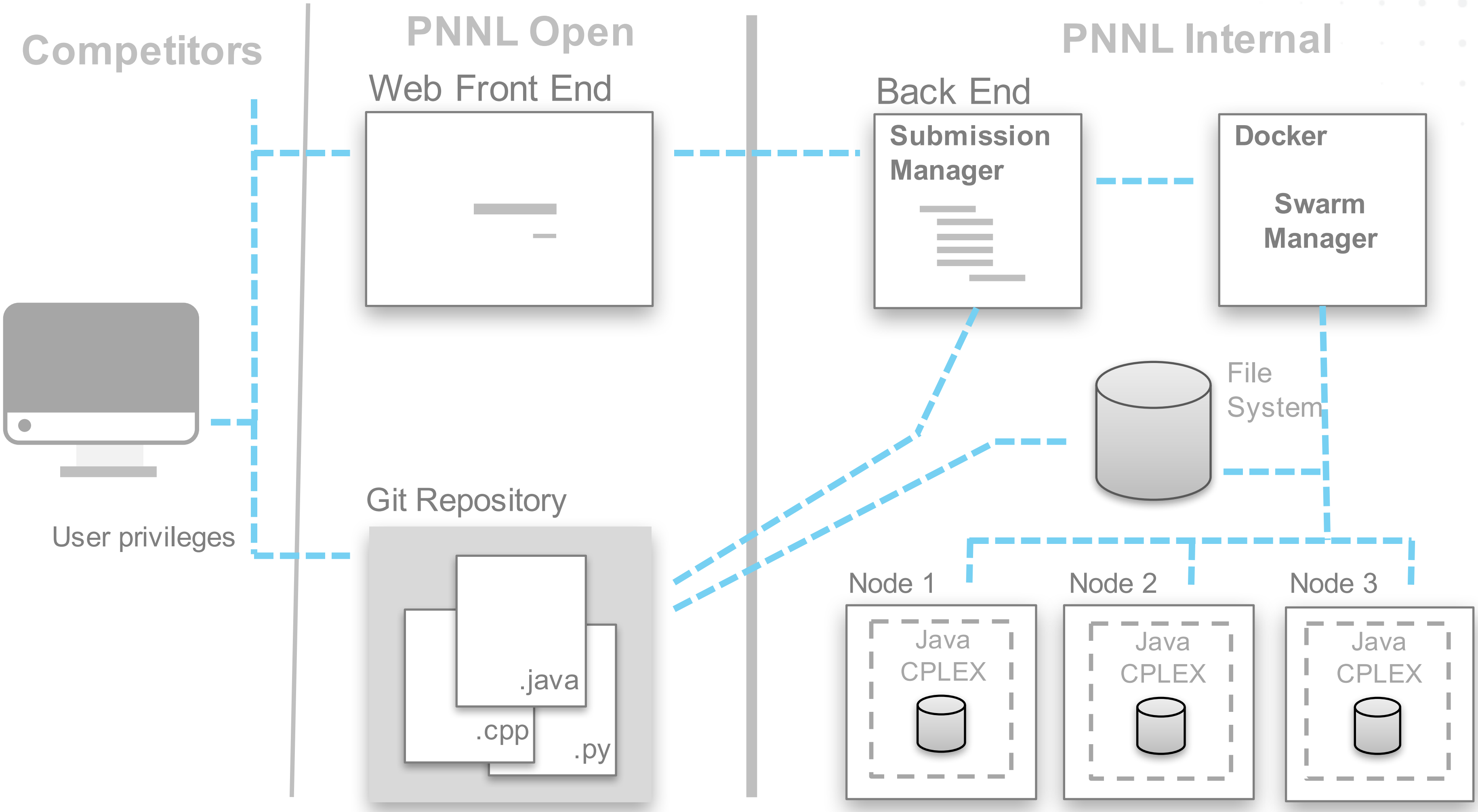
Competition Evaluation Platform

Automated evaluation platform to provide fair environment for competition – solution methods assessed using same computation environment and software versions.



Competition platform is for evaluation; NOT a development environment.

Community Participation Opportunities

- Competitors – Individuals, organizations, and/or teams
- Industry sponsors – Provide feedback on problem selection and/or formulation, data sets, competitor development funding, and/or prize funding
- Contributors/sponsor – Provide supporting materials and licensed software, join forum discussions
  - CPLEX
  - Gurobi
  - Knitro
  - Xpressmp
  - MATLAB & MATPOWER
  - GAMS
  - …more to come

Conclusions

- Recent advances in several disciplines (advanced computing, optimization solvers, applied mathematics, power systems engineering, etc.) offer the potential to develop new approaches to solving OPF, Unit Commitment, and related grid optimization problems.
- New grid optimization algorithms are struggling to gain traction due to a lack of large-scale, detailed, public grid datasets and the lack of mechanisms for rigorous and transparent validation.
- ARPA-E's GRID DATA program (launched in early 2016) is building large-scale, realistic, validated, open-access power system models and scenarios (both transmission and distribution systems).
- ARPA-E is exploring the organization of a series of grid optimization algorithm competitions.
- ***We hope to release a Request-For-Information (RFI) in Summer 2016 to seek detailed community feedback.***

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