CHANGING WHAT'S POSSIBLE

Optimal Power Flow Competition Introduction

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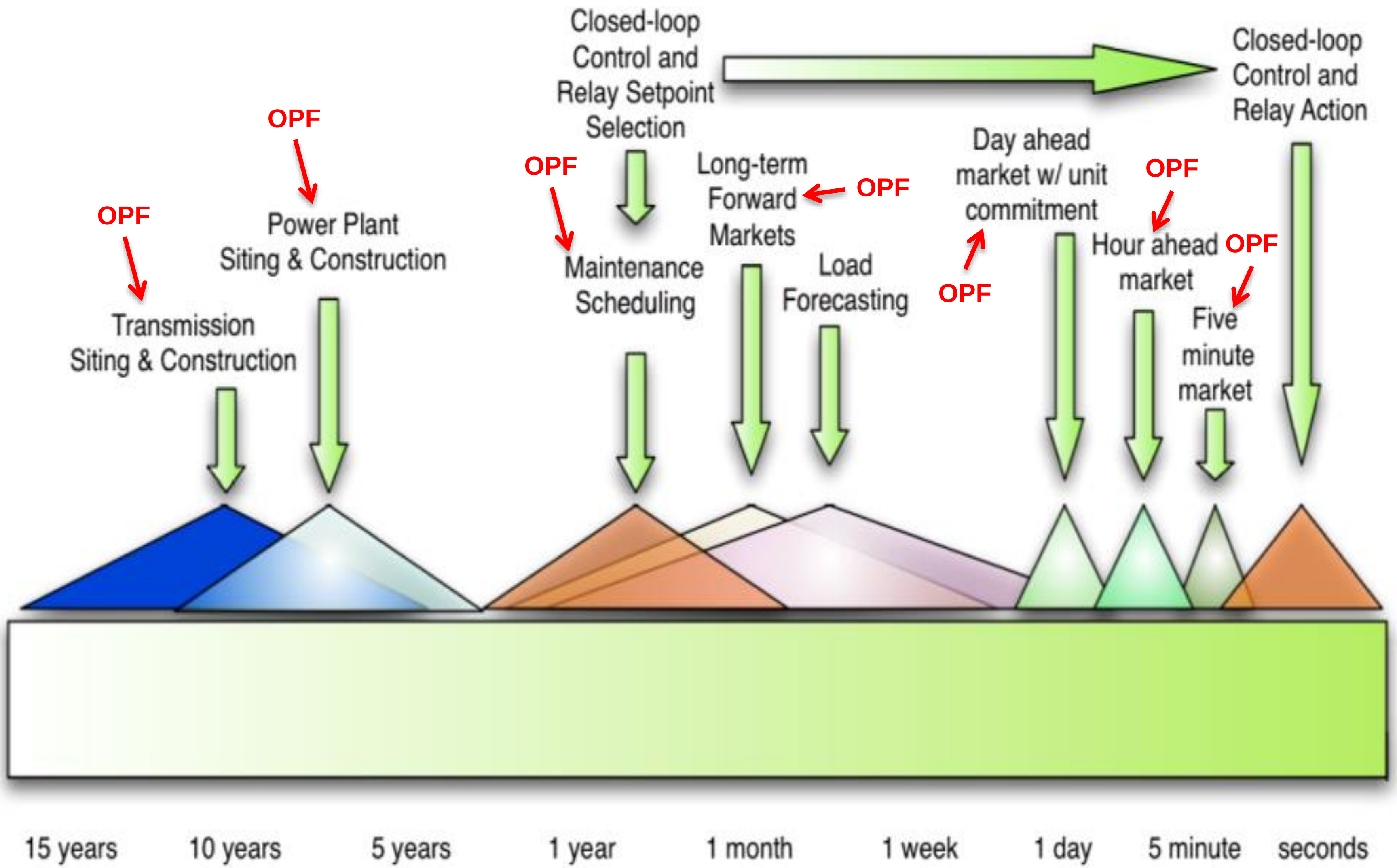
U.S. Department of Energy

GRID DATA Kickoff Meeting

Denver, CO, March 30-31, 2016

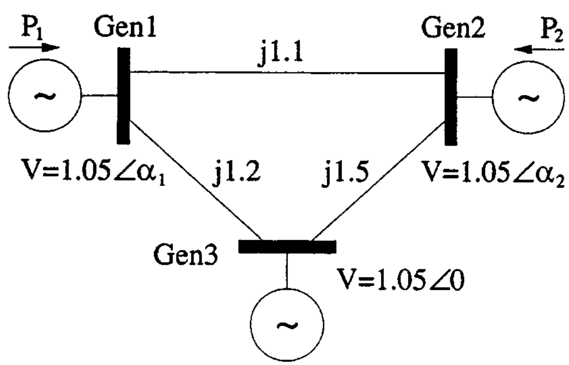
U.S. DEPARTMENT OF ENERGY

Electric grid operations depend on OPF

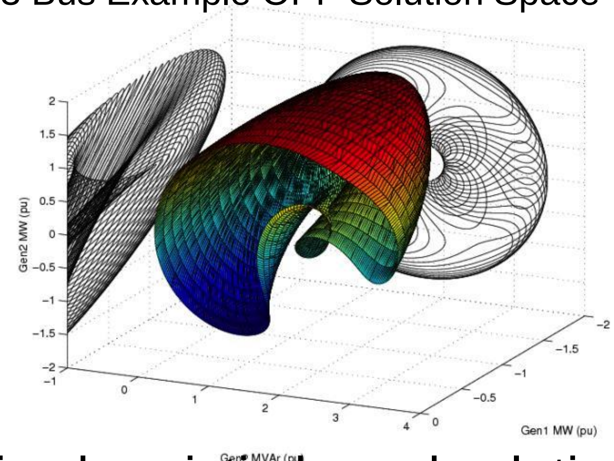


Optimizing Grid Power Flows is Hard

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



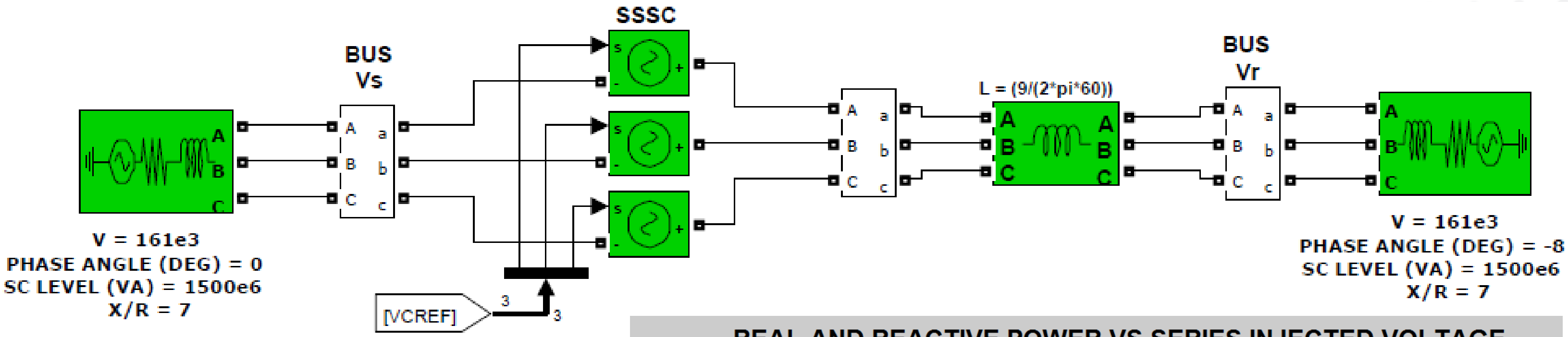
3 Bus Example OPF Solution Space



- 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.)
- Existing OPF tools do not guarantee a physical solution. (Feasibility of solution must be assessed separately.)

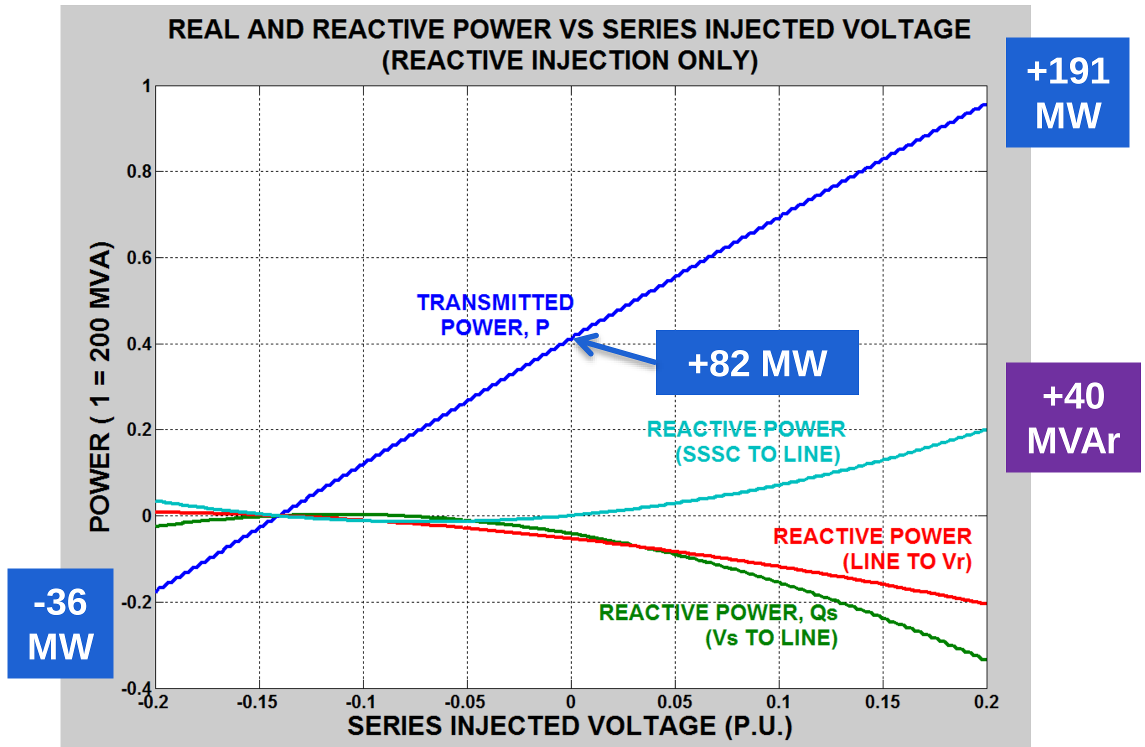
- I.A. Hiskens and R.J. Davy, "Exploring the power flow solution space boundary", IEEE Transactions on Power Systems, Vol. 16, No. 3, August 2001, pp. 389-395.
- M. Ilic et al., "Optimal voltage management for enhancing electricity market efficiency" FERC Staff Technical Conference, June 2014

REACTIVE SERIES POWER INJECTION CAN RAISE, LOWER, OR REVERSE TRANSMITTED POWER



161 kV TRANSMISSION LINE EXAMPLE:

- *P = 82 MW WITH NO INJECTED VOLTAGE*
- *P = +191 MW WITH +0.2 P.U. VOLTAGE INJECTION (SSSC OUTPUT = +40 MVAr)*
- *P = -36 MW WITH -0.2 P.U. VOLTAGE INJECTION (SSSC OUTPUT = +7 MVAr)*



Example Cost Savings Study

Case	Scenario	PJM Generator Voltage Dispatch	PJM Generation Cost ($)	PJM Load Charge ($)	PJM Generator Revenue ($)	PJM Losses (pu)	PJM Merchandise Surplus ($)	PJM LMP Ranges ($/MW-Hr)
Base	N/A	Fixed	1,712,115	N/A	N/A	11.13	N/A	N/A
1	A	Fixed	1,607,990	2,605,773	2,669,987	11.41	-13,033	-108 – 1,145
2	A	Variable	1,456,763	2,546,214	2,594,721	10.44	-39,212	0 – 56
3	B	Fixed	1,626,570	2,523,992	2,769,975	11.68	-186,475	-785 – 344
4	B	Variable	1,454,207	2,537,931	2,587,545	11.27	42,725	0 – 55
5	C	Fixed	1,722,957	3,059,155	2,775,109	11.28	284,046	-158 – 1,032
6	C	Variable	1,605,320	2,795,326	2,750,877	11.84	44,449	0 – 55

TABLE I

BASE CASE PROPERTIES AND ECONOMIC DISPATCH RESULTS FOR THREE SCENARIOS: (A) NORMAL OPERATION WITH AND WITHOUT VOLTAGE OPTIMIZATION (CASES 1&2); (B) NORMAL OPERATION (RETIRED PLANTS) WITH AND WITHOUT VOLTAGE OPTIMIZATION ((CASES 3&4); (C) ECONOMIC DISPATCH WITH 6% RESERVE WITH AND WITHOUT VOLTAGE OPTIMIZATION (CASES 5&6)

No Voltage Dispatch (DC-OPF)

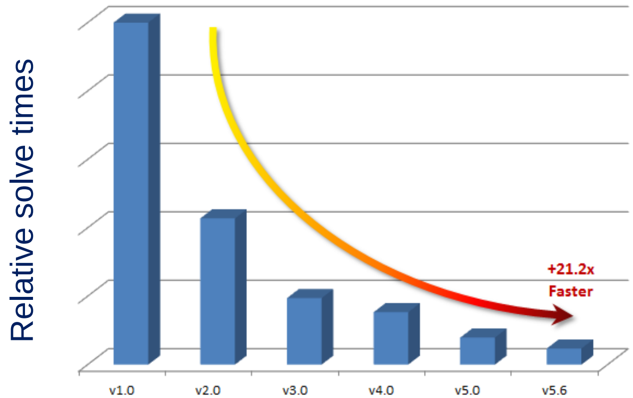
Voltage Dispatch (AC-OPF)
Savings: $117,637 (6.8%)

M. Ilic et al., “Optimal voltage management for enhancing electricity market efficiency” FERC Staff Technical Conference, June 2014

Why now?

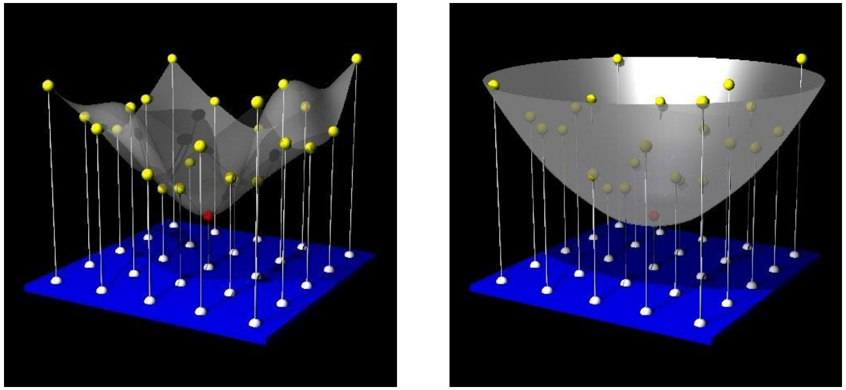
- Continued reductions in advanced computing costs
- Rapid optimization solver improvements (especially MIP)
- Reevaluation of alternative problem formulations (IV Formulation)
- Fast, accurate convex relaxations for OPF (SDP/QC/SOCP relaxations)
- Distributed approaches to OPF (ADMM or other methods)

Gurobi (MIP) Improvement



Source: Gurobi

Convex Relaxation



http://www.idi.ntnu.no/~schellew/convexrelaxation/ConvexRelaxation.html

Why Have New OPF Methods Struggled to Gain Traction?

- Lack of sufficiently detailed, large-scale, validated test systems. Difficult to establish the scalability of new methods and their ability to accommodate real-world, practical challenges.

- Large gap between idealized (simplified) problem formulations in research community and industry problems.

- Lack of comprehensive, fair, consistent mechanisms for benchmarking different solution methods.

Intersection of Disparate Communities

Electric Power Engineering

- Deep knowledge of grid operations and utility needs.
- Expertise in new utility technology adoption.

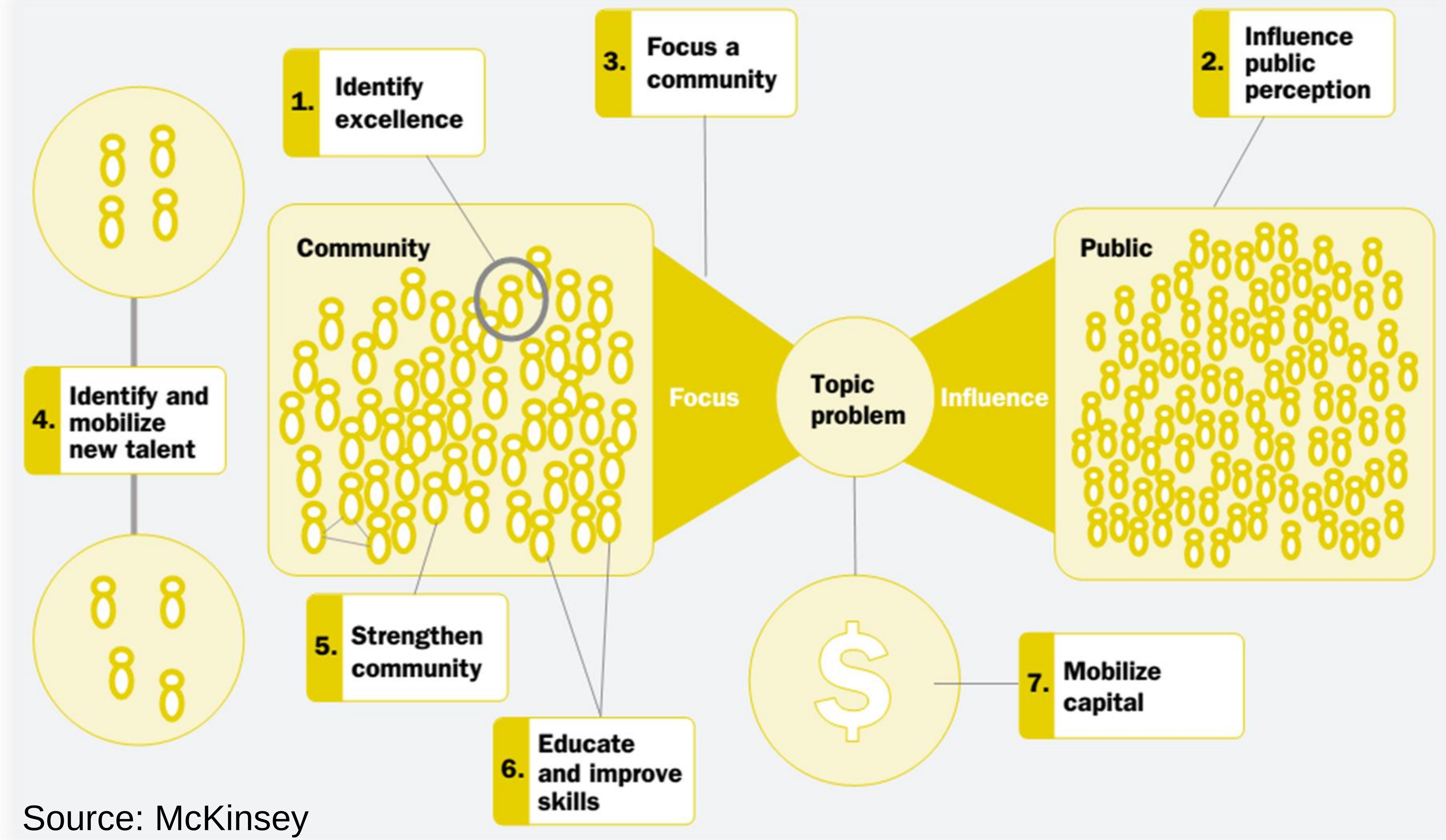
High Performance Computing

- Deep knowledge of parallelization, new computational resources.
- Expertise in robust software design and development.

Optimization & Applied Mathematics

- Deep knowledge of model design and optimization solution methods.
- Expertise in solution validation.

Prize Contests



Source: McKinsey

Competition Success Stories

Longitudinal Prize of 1714

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

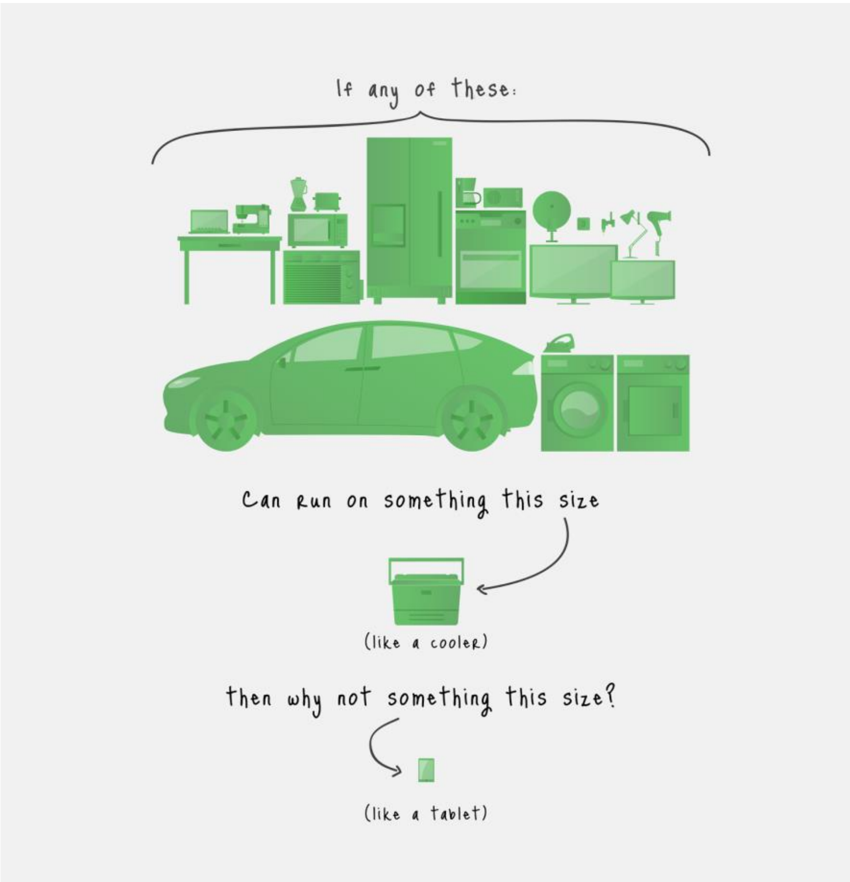
Systems integration:
SLAM+Planning+Mechatronics
= Self-driving car

$1M Prize
Winner 10.6% improvement

CHANGING WHAT'S POSSIBLE

Power Related Competitions

Google/IEEE Little Box Challenge
(2014-2016)



IEEE Forecasting Competition

Held in 2012 & 2014
40% reduction in RMSE

IEEE Competition on "Application of Modern Heuristic Optimization Algorithms for Solving Optimal Power Flow Problems"

Initial competition in 2014. Additional competition planned in 2015

IEEE PES
Power & Energy Society™

OPF Competition

Detailed, Large Power System Model

- Network topology (incl. realistic line limits, voltage limits, etc.)
- Generator locations and characteristics (physical limits and cost curves)
- Contingency lists (incl. complex multi-element contingencies)
- Other control device characteristics: LTC, PST, Capacitor Banks, Power Flow Control Devices (locations, allowed setpoints, etc.).
- Controllable demand characteristics
- Energy storage

Operation Snapshots (1000s)

- Demand characteristics (at each bus)
- Wind/Solar generation
- Transmission and generation availability
- Other temporary constraints

Participants develop new modeling approaches and solution algorithms using provided datasets.

- Evaluation and scoring of solutions (semi-automated, quantitative, transparent scoring required)

ADVANCED BULK POWER SYSTEM OPTIMIZATION TECHNOLOGIES WORKSHOP

November 13-14, 2014

ARPA-E held a public workshop – "Advanced Bulk Power System Optimization Technologies" from November 13-14, 2014 in Arlington, VA.

Tremendous recent advances in Electric Power Engineering, Optimization and Applied Mathematics, and High Performance Computing offer many new opportunities to dramatically improve the operation of electric transmission systems. These technologies also promise to play an important role in the cost-effective integration of variable renewable energy sources. Many new power system optimization methodologies have been proposed in recent years, including new approaches to solving optimal power flow and unit commitment problems. However, thus far, many of the proposed advances lack validation on realistic, large scale test datasets and their operational limits are poorly understood. These limitations are slowing adoption by industry.

Conclusion: OPF competition challenging, feasible, attractive, but need to focus on dataset creation first.

Algorithm Competition Requirements

1. Realistic, challenging benchmarking test systems

1. 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

2. 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

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
- Identify and build/acquire required resources
  - Solvers, programming languages, forum
- Outreach & Communications

Pacific Northwest NATIONAL LABORATORY

ARIZONA STATE UNIVERSITY

THE UNIVERSITY of WISCONSIN MADISON

Competition Risks: Problem & Dataset Selection

- Competition problem could be too easy or too difficult to engage the right research community stakeholders.
- Datasets could have too little detail, limiting practical usefulness.
- Datasets could have too much detail, difficult to interpret and use.
- Problem definition could be overconstrained/underconstrained.
- Poor problem specification could result in algorithms not easily adaptable by industry (due to regulations, market design requirements, etc.).
- Competition results could turn out to be narrowly applicable (to particular network configurations, regions of the country, etc.).
- The rules constructed inadvertently rule out a promising solution technique (e.g. by using hardware that discourages distributed solutions or those with extensive memory requirements).

Competition Risks: Scoring, Evaluation, Winning

- Competitors (especially in later phases) could fail to sufficiently engage the power industry and established vendors.
- Insufficient incentives to encourage widespread participation (especially existing vendor community).
- Poorly designed scoring targets and/or objective function construction could be mis-aligned with industry priorities.
- Poorly designed scoring targets could make it easy to “game the system,” resulting in algorithms of minimal practical use.

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