Cornell University

PSERC

Project 22: "Development and Testing of New Tools"

Developing and Testing Improved Tools for Power System Planning and Operation under Uncertainty

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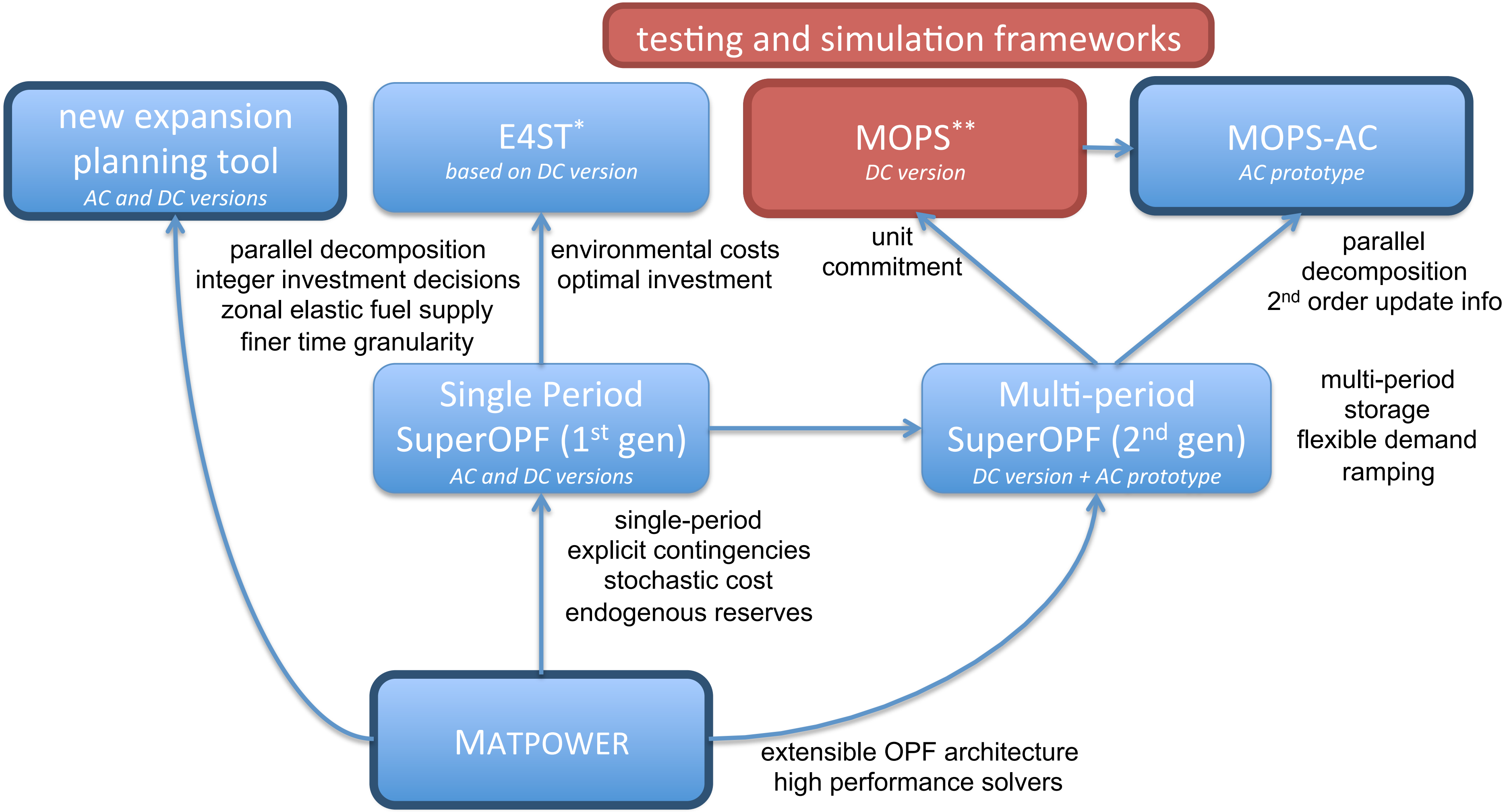
U.S. DEPARTMENT OF ENERGY

CERTS
Consortium for Electric Reliability Technology Solutions

Overview

- **Background** – motivation, context, status
- **MATPOWER** – updates and direction
- **MOPS** – MATPOWER Optimal Power Scheduler
- **Testing MOPS** – simulation framework, tests
- New **expansion planning tool**
- **AC convergence** of MOPS

Tools Overview



* **E4ST** – **E**ngineering, **E**conomic, **E**nvironmental **E**lectricity **S**imulation **T**ool, *formerly SuperOPF Planning Tool*.

** **MOPS** – **M**ATPOWER **O**ptimal **P**ower **S**cheduler, *based on Multi-period SuperOPF with Unit Commitment (3rd generation)*

Background - Motivation

- Tool Development
  - Improve on the software tools in current use for planning and operation of electric power systems, especially in light of industry trends:
    - uncertainty (renewables, environmental regulation, etc.)
    - new technologies (storage, demand side participation, microgrids, etc.)
- Tool Testing
  - Demonstrate and measure the benefits of our approach over current system operator practice.
    - Compare stochastic approach to traditional deterministic approach using MOPS.
    - Compare receding horizon structure to day-at-a-time planning using MOPS.
- Impacts
  - Small improvements in efficiency can have significant economic and reliability impacts.
  - Open source tools have far-reaching impact on research beyond this program.

Background - Context

- Tool Development
  - MOPS
    - design does not preclude AC network model
    - co-optimizing energy, endogenous reserves for contingencies and load-following
    - internalized ramping costs
    - scenario tree recombination, preserves multistage structure of decisions
  - new expansion planning tool (basis for E4ST v2)
    - AC or DC network model
    - binary investment/retirement decisions and costs
    - elasticity of fuel supply
    - more time granularity
- Tool Testing
  - performance tested in context of original problem with non-anticipativity, not approximations made to make problem tractable (multi-stage decisions vs. two-stage)

Background - Status

- Tool Development
  - MATPOWER
    - released versions 5.0 and 5.1 in past year
    - expect version 6.0 with MOPS in a few months
    - moving toward public open source project with open development paradigm
  - E4ST
    - new web site (Schulze project) to host data, tools, results
    - version 1 of core solver software stable
      - public distribution requires additional cleanup and documentation
  - MOPS
    - being actively used for testing
    - integration into MATPOWER 6, requires more documentation, cleanup of code
    - receding horizon requires further modifications (partially completed)
  - next gen planning tool, foundation for E4ST v2
    - prototype complete, being used in testing
    - integrate into MATPOWER or separate E4ST v2 project when ready

Background - Status

- Tool Development (continued)
  - AC version of MOPS
    - current prototype not ready for prime time due to convergence challenges
    - explore Newton-based coordination updates to address convergence problems
- Tool Testing
  - integrated simulation platform for MOPS testing, two-settlement, receding horizon, etc.
    - original attempt at grand unified simulator bogged down in details
    - two settlement simulator running
    - receding horizon delayed
  - two stage framework, stochastic vs. deterministic
    - lots of obstacles in design of 118 bus comparisons, calibration of inputs, structure of simulation
    - comparisons almost complete, expect paper submission in Aug or Sep
  - receding horizon
    - required additional changes to MOPS (nearly complete)
    - requires more general simulator, pursuing getting a student to help with this
    - additional challenges expected as we move to generating wind scenarios on the fly

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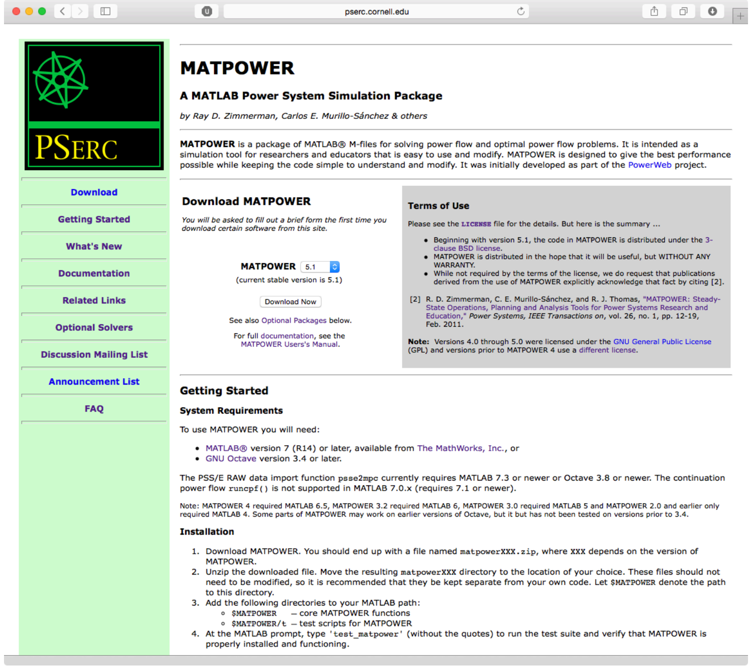
MATPOWER

Free, open-source power system simulation environment with extensible OPF and interfaces to state-of-the-art solvers.



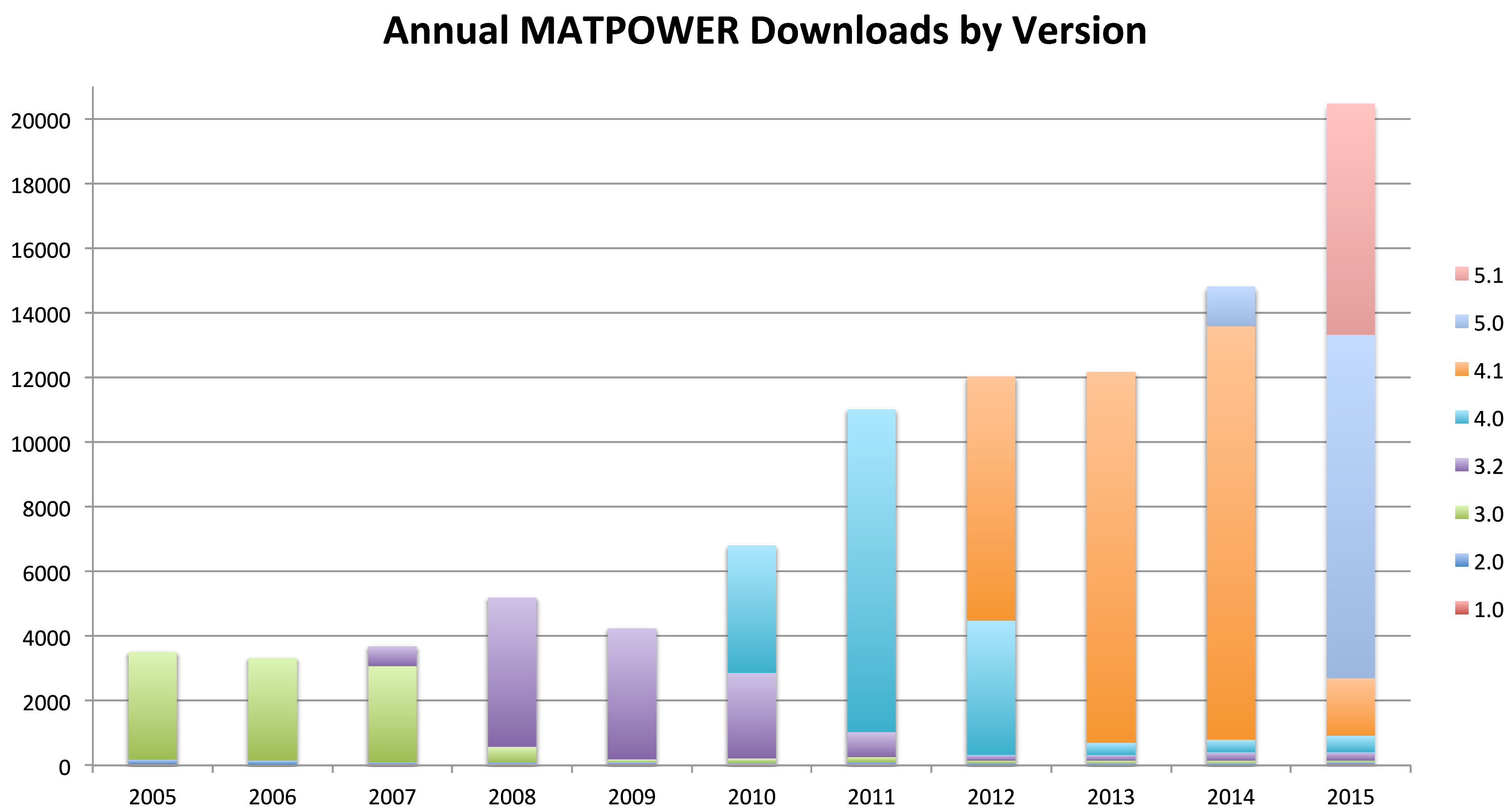
http://www.pserc.cornell.edu/matpower/

– used worldwide in teaching, research, industry
– momentum & impact continues to grow
  - **1062 citations** of 2 main MATPOWER papers*
  - **664 citations** of MATPOWER software/manual*
– serves as foundation for all tools in this project

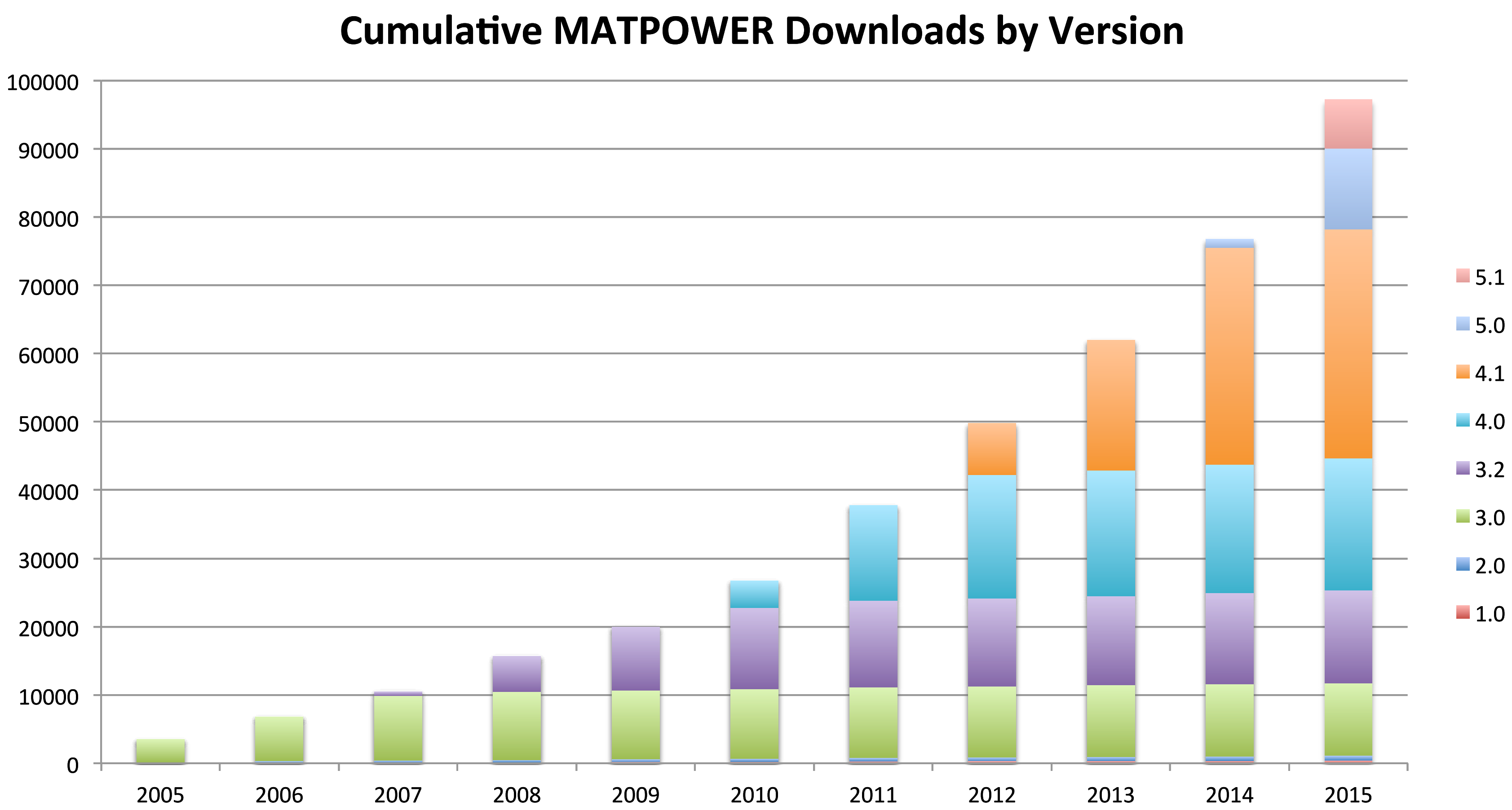
R. D. Zimmerman, C. E. Murillo-Sánchez, and R. J. Thomas, "MATPOWER Steady-State Operations, Planning and Analysis Tools for Power Systems Research and Education," *Power Systems, IEEE Transactions on*, vol. 26, no. 1, pp. 12-19, Feb. 2011.

* *Google Scholar, 8/3/15*

Annual MATPOWER Downloads



Cumulative MATPOWER Downloads



MATPOWER Releases – v5.0

- Version 5.0b1 – *released July 1, 2014*
  - continuation power flow
  - application of SDP relaxations of PF equations
  - extensible options architecture
  - tools for detailed reporting of case data, connectivity, manipulating islands
  - PSS/E RAW import capability
  - new and updated support for 3rd party solvers
- Version 5.0 (final) – *released Dec 17, 2014*
  - enhanced PSS/E RAW import, more robust, support for more versions
  - soft limits on DC OPF branch flows
  - more user settable parameters for default interior point solver
  - performance enhancements
  - bug fixes

MATPOWER Releases – v5.1

- Version 5.1 (final) – *released Mar 20, 2015*
  - new license
    - switched to more permissive 3-clause BSD license from GPL v3
  - new case files
    - four new case files representing parts of European high voltage grid
    - models ranging from 89 to 9421 buses (largest system distributed with MATPOWER)
  - new documentation
    - on-line function reference at http://www.pserc.cornell.edu/matpower/docs/ref/
  - new features
    - unified interface for 3rd party mixed integer solvers for MILP/MIQP
    - support for PARDISO as linear solver used by interior point algorithm for AC OPF
    - new and updated support for 3rd party solvers, including OPTI Toolbox (CLP, GLPK, IPOPT), IPOPT-PARDISO
    - network reduction toolbox *(Tylavsky, Zhu)*
  - performance enhancements
  - other refinements and bug fixes

New License

BSD or MIT style license

- permissive
- short and to the point
- lets people do what they want, as long as they
  - provide attribution
  - don't hold you liable
- leaves open commercialization options
- E.g. FreeBSD, jQuery, Rails

Required	Permitted	Forbidden
License and copyright notice	Commercial Use	Hold Liable
	Distribution	
	Modification	
	Private Use	
	Sublicensing	

GPL license

- copyleft
- legally complex
- requires distribution of any modifications or derivatives to be under same terms
- designed to keep research results from transitioning to proprietary products
- E.g. Linux, Git, WordPress

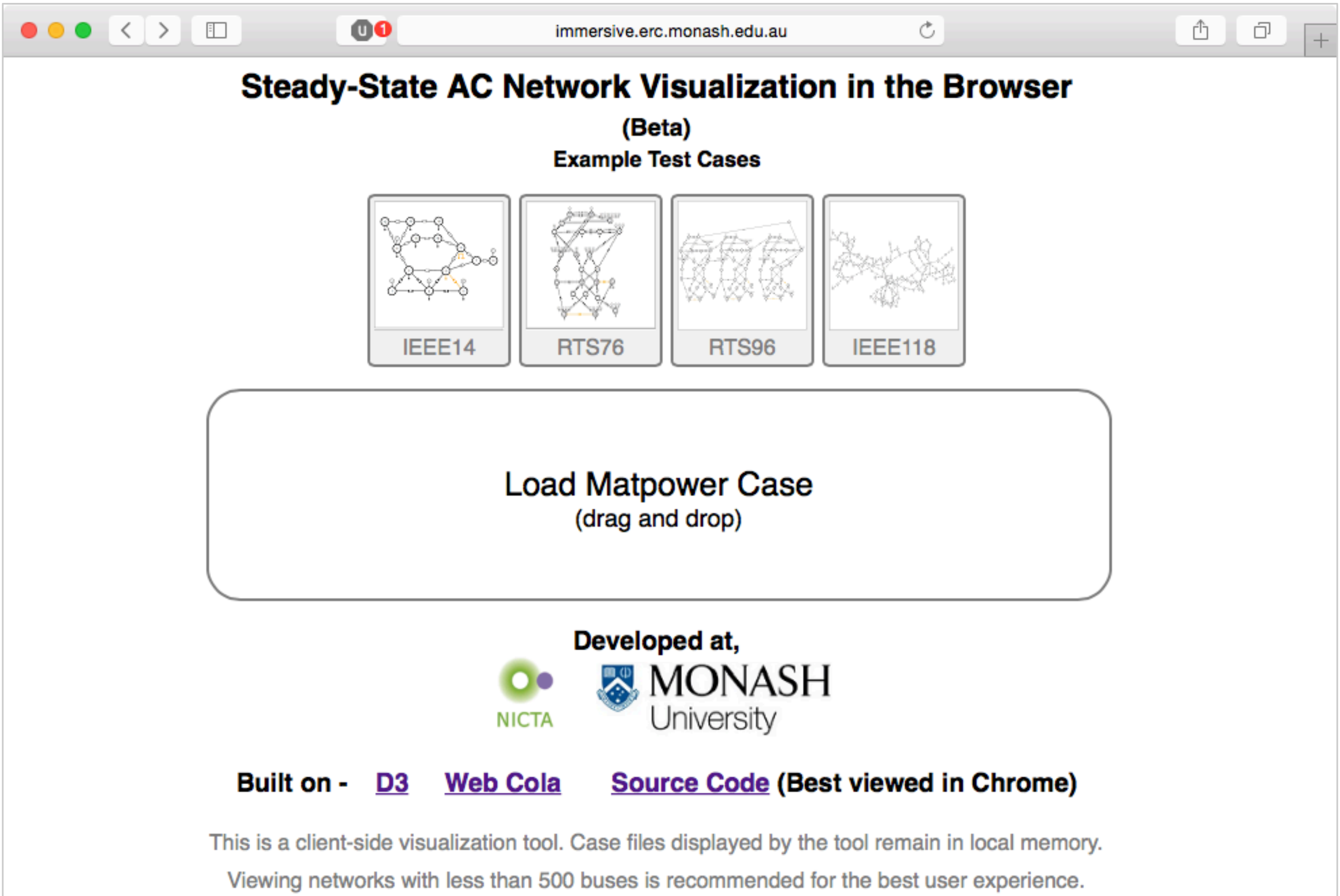
Required	Permitted	Forbidden
Disclose Source	Commercial Use	Hold Liable
License and copyright notice	Distribution	Sublicensing
State Changes	Modification	
	Patent Grant	
	Private Use	

Sources:
- Why you should use a BSD style license for your Open Source Project, http://www.freebsd.org/doc/en_US.ISO8859-1/articles/bsdl-gpl/article.html
- http://choosealicense.com/

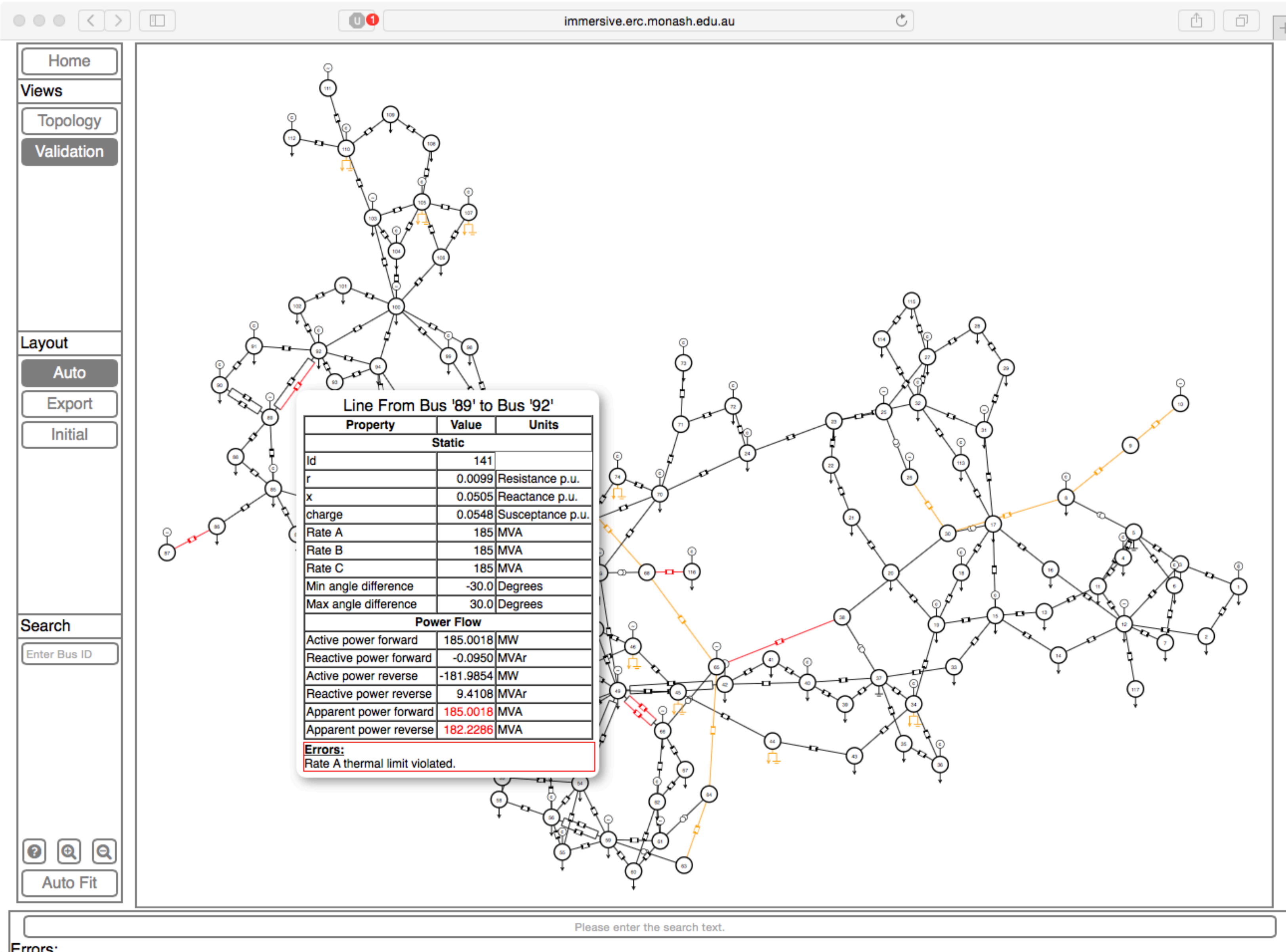
PARDISO – Large-scale AC OPF

- Bottleneck in primal-dual interior point solvers (IPOPT, Knitro, MIPS) is the Newton update step, i.e. solving $Ax = b$
- PARDISO – http://www.pardiso-project.org
  - thread-safe, high-performance, robust, memory efficient software for solving large sparse linear systems of equations on shared/distributed-memory multiprocessors
- Largest AC OPF model solved is 3000-bus Polish model with 63-contingencies
  - roughly equivalent to 193,000-bus AC OPF, plus extras
  - size previously limited by RAM (64 GB on 12-core machine)
- When using MIPS, switching from Matlab's built-in `x=A\b` to PARDISO results in …
  - 30x speedup on 12-core machine
  - order of magnitude decrease in RAM requirement
- IPOPT-PARDISO – currently MATPOWER's fastest AC OPF solver
  - solves this case in ~18 minutes on my laptop (2014 MacBook Pro)
  - developers looking for large-scale systems to test their solver, MATPOWER integration
  - IPOPT-PARDISO distributed on PARDISO site under "MATPOWER libraries"
  - **MATPOWER is helping to drive advances in high-performance linear system solvers**

STAC


immersive.erc.monash.edu.au
Steady-State AC Network Visualization in the Browser
(Beta)
Example Test Cases
IEEE14
RTS76
RTS96
IEEE118
Load Matpower Case
(drag and drop)
Developed at,
NICTA
MONASH University
Built on - D3 Web Cola Source Code (Best viewed in Chrome)
This is a client-side visualization tool. Case files displayed by the tool remain in local memory.
Viewing networks with less than 500 buses is recommended for the best user experience.

STAC


immersive.erc.monash.edu.au
Home
Views
Topology
Validation
Layout
Auto
Export
Initial
Search
Enter Bus ID
Auto Fit
Line From Bus '89' to Bus '92'
Property Value Units
Static
Id 141
r 0.0099 Resistance p.u.
x 0.0505 Reactance p.u.
charge 0.0548 Susceptance p.u.
Rate A 185 MVA
Rate B 185 MVA
Rate C 185 MVA
Min angle difference -30.0 Degrees
Max angle difference 30.0 Degrees
Power Flow
Active power forward 185.0018 MW
Reactive power forward -0.0950 MVAr
Active power reverse -181.9854 MW
Reactive power reverse 9.4108 MVAr
Apparent power forward 185.0018 MVA
Apparent power reverse 182.2286 MVA
Errors:
Rate A thermal limit violated.
Please enter the search text.
Errors:

MATPOWER Development – v6.0-dev

- ZIP load model
  - experimental feature based on contributed code
- performance enhancements
  - large speedups when running many small problems
- MOPS integration *(Ray)*
  - code cleanup
    - GNU Octave compatibility
    - splitting program options from input data structures
    - adding UC to supporting code for data input, auto-generation of sensible default data
  - documentation, manuals and in code
  - automated tests
  - tutorial examples
- MOPS development – beyond MATPOWER 6 *(Carlos)*
  - probabilistic initial state features needed for receding horizon application
  - AC prototype convergence improvement

MATPOWER Project Directions

- First steps to address need for a sustainable long-term plan.
- Apply for 3 years of funding through NSF SI^2 (Software Infrastructure for Sustained Innovation) program.
  - Goals include to "support the **creation and maintenance** of an innovative, integrated, reliable, sustainable and accessible **software ecosystem** providing new capabilities that **advance and accelerate scientific inquiry** and application at unprecedented complexity and scale."
  - Division of Electrical, Communications and Cyber Systems "is particularly interested in proposals which provide wider, more flexible access to more advanced general algorithms in the areas of electronic and photonics device simulation (accounting for quantum many body effects), computational intelligence, **nonlinear optimization** or **energy system design**."
- Move MATPOWER to true public open source project/open dev paradigm
  - public code repository, multiple committers
  - public bug tracking facility, user/developer forums, improved web-site
  - core project documents defining project, goals, policies, how to contribute
  - streamlined "on ramps" for users and developers
  - effective process in place for incorporating contributions and feedback, including from other CERTS projects

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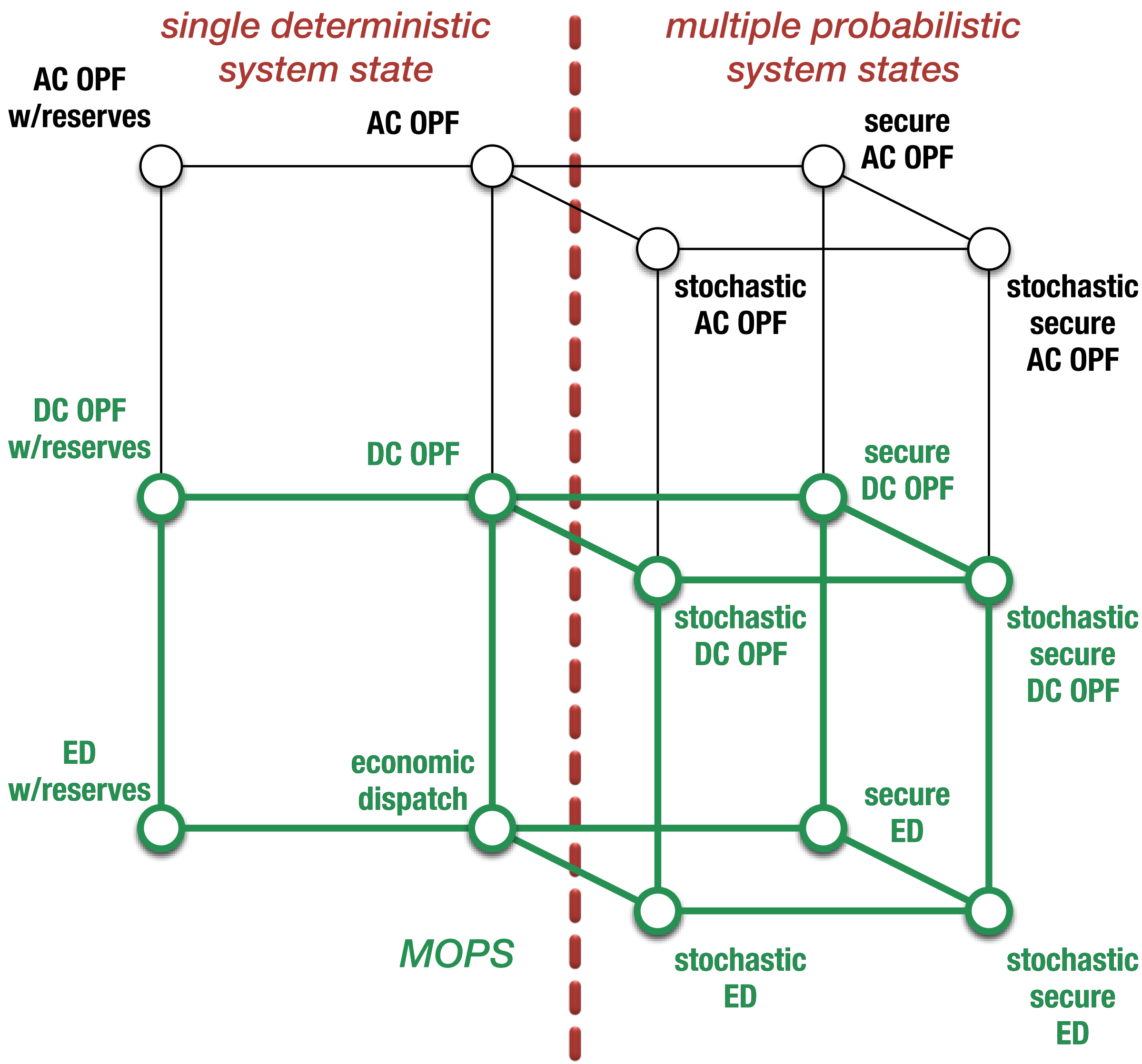
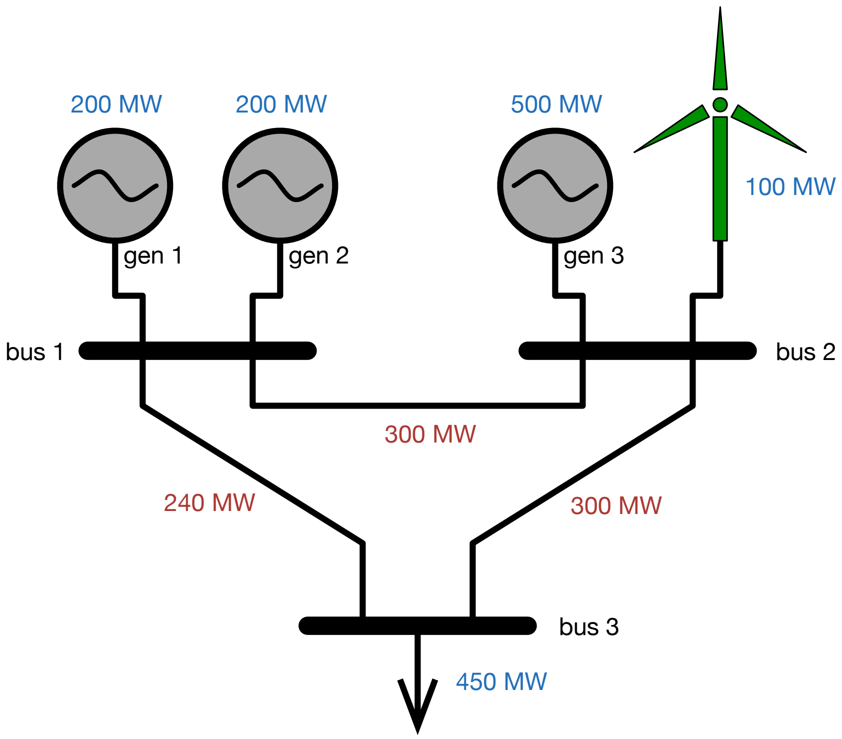
MOPS Continuous Single Period Problems

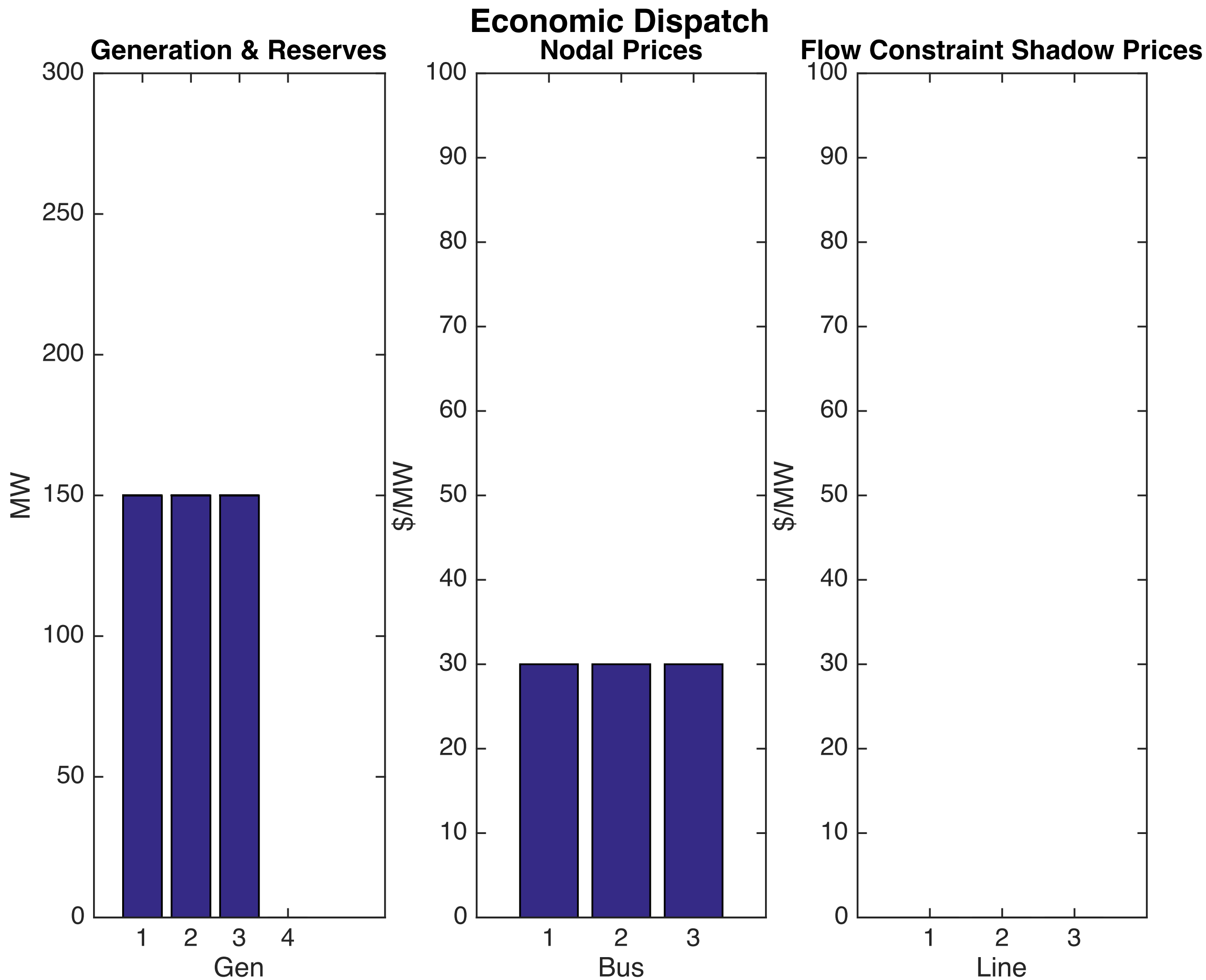


Tutorial Example System

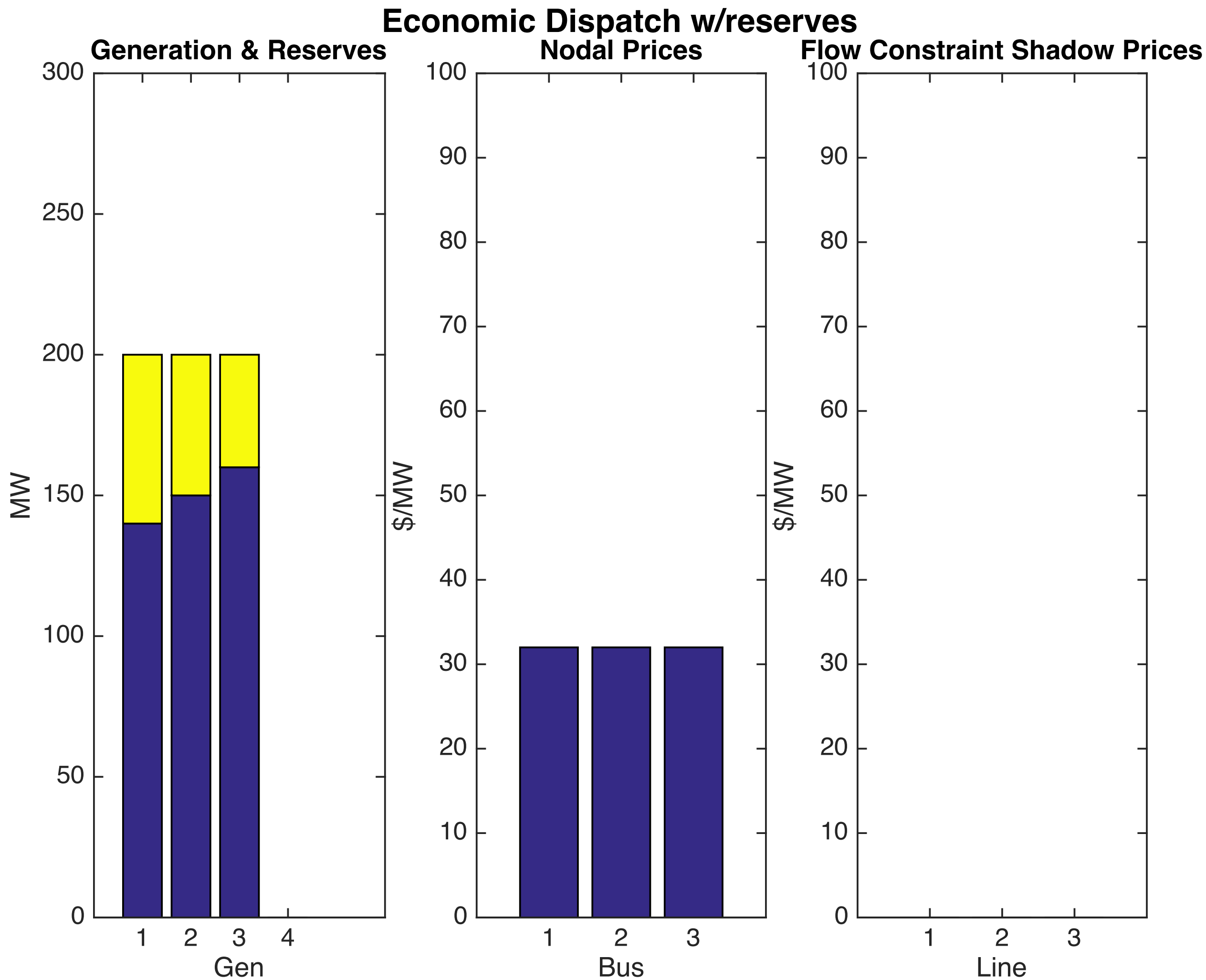
- 3-bus triangle network
- generators
  - 2 identical 200 MW gens at bus 1, diff reserve cost
  - 500 MW gen at bus 2
  - all 3 have identical quadratic generation costs
- load 450 MW at bus 3, curtailable @ $1000
- branches
  - 300 MW limit, line 1–2
  - 240 MW limit, line 1–3
  - 300 MW limit, line 2–3
- adequacy requirement
  - reserve requirement
    - 150 MW limit
  - contingencies
    - generator 2 at bus 1
    - line 1–3
- wind
  - 100 MW unit at bus 2
  - 3 samples of normal distribution around 50 MW



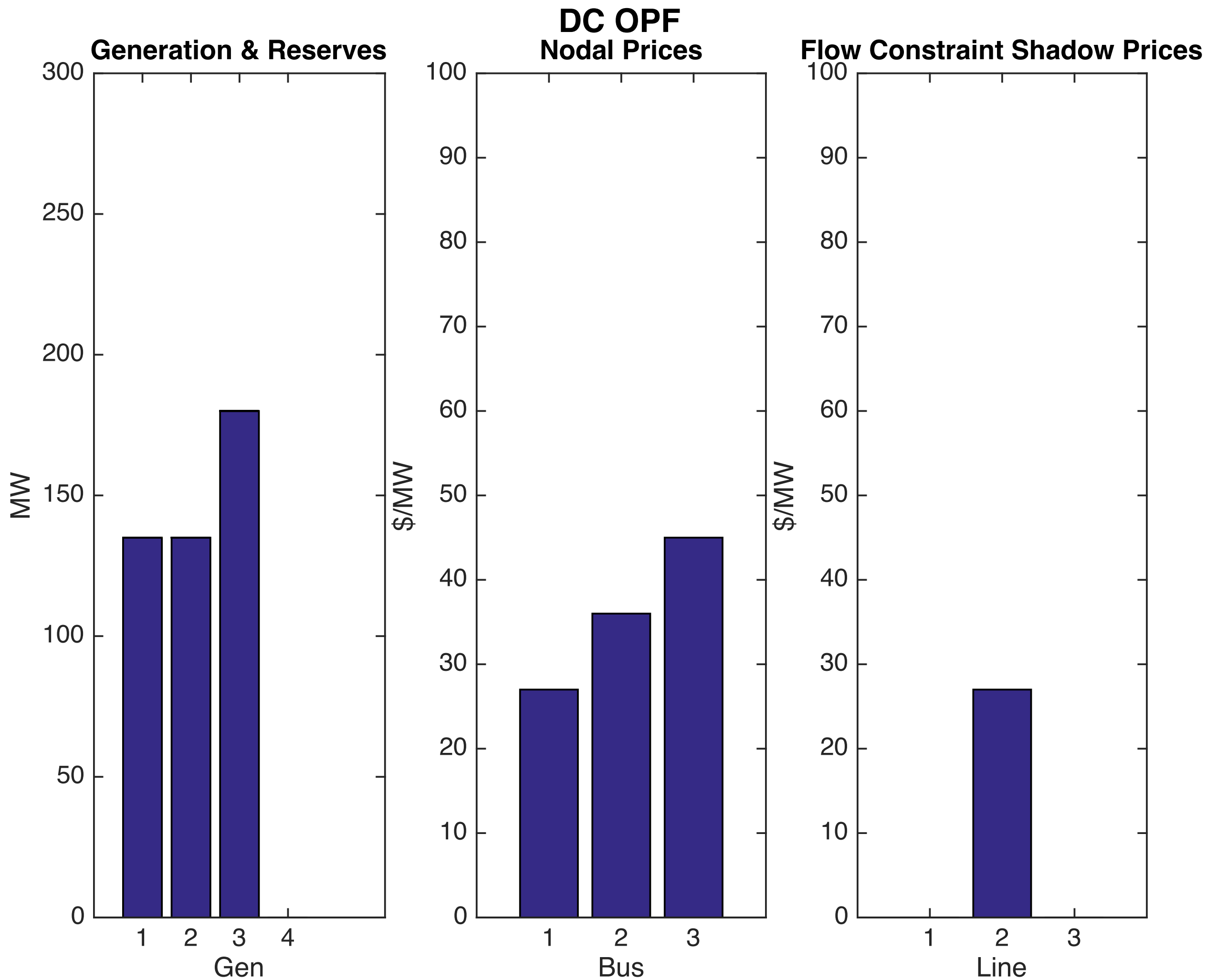
Single Period Continuous Examples



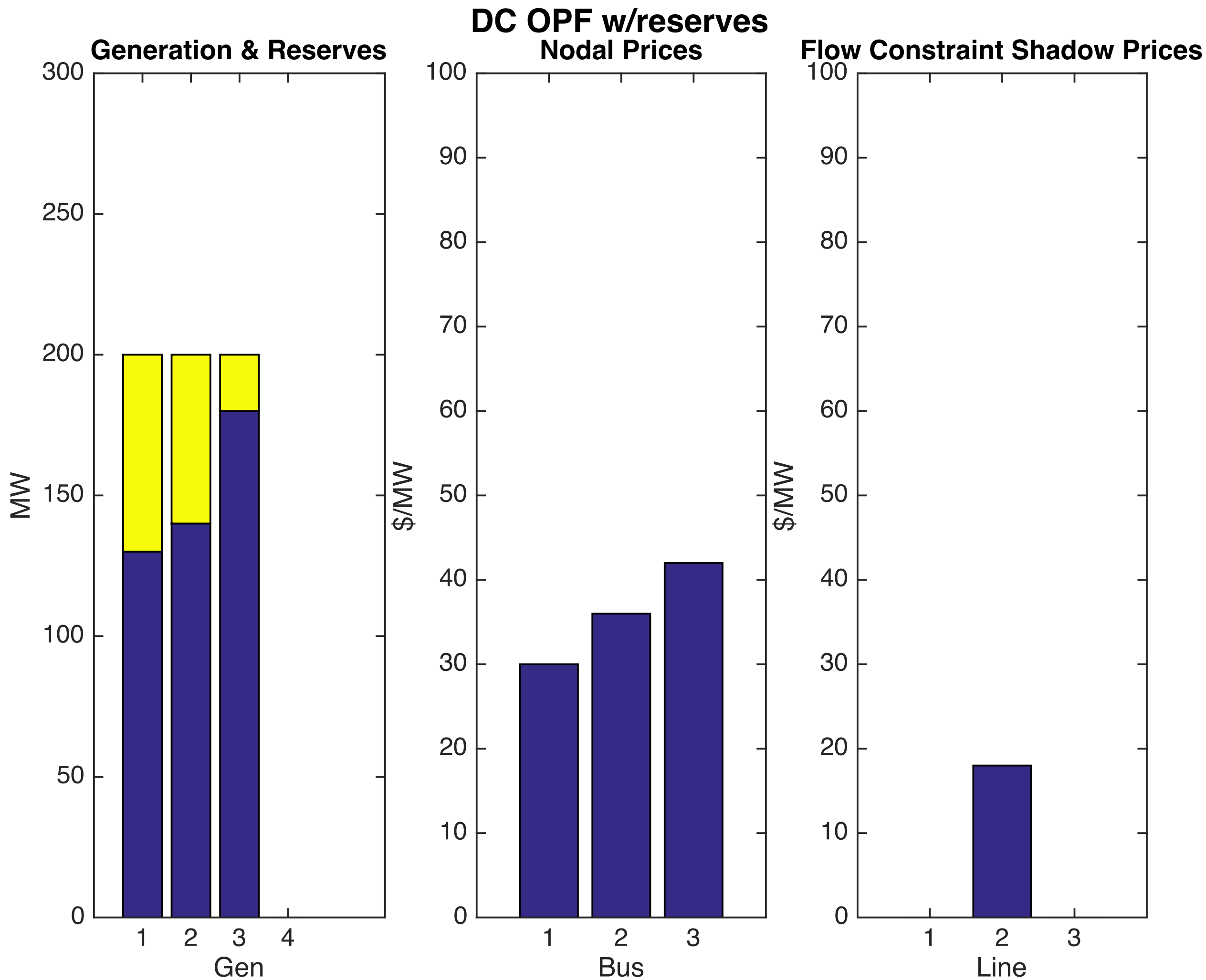
Single Period Continuous Examples



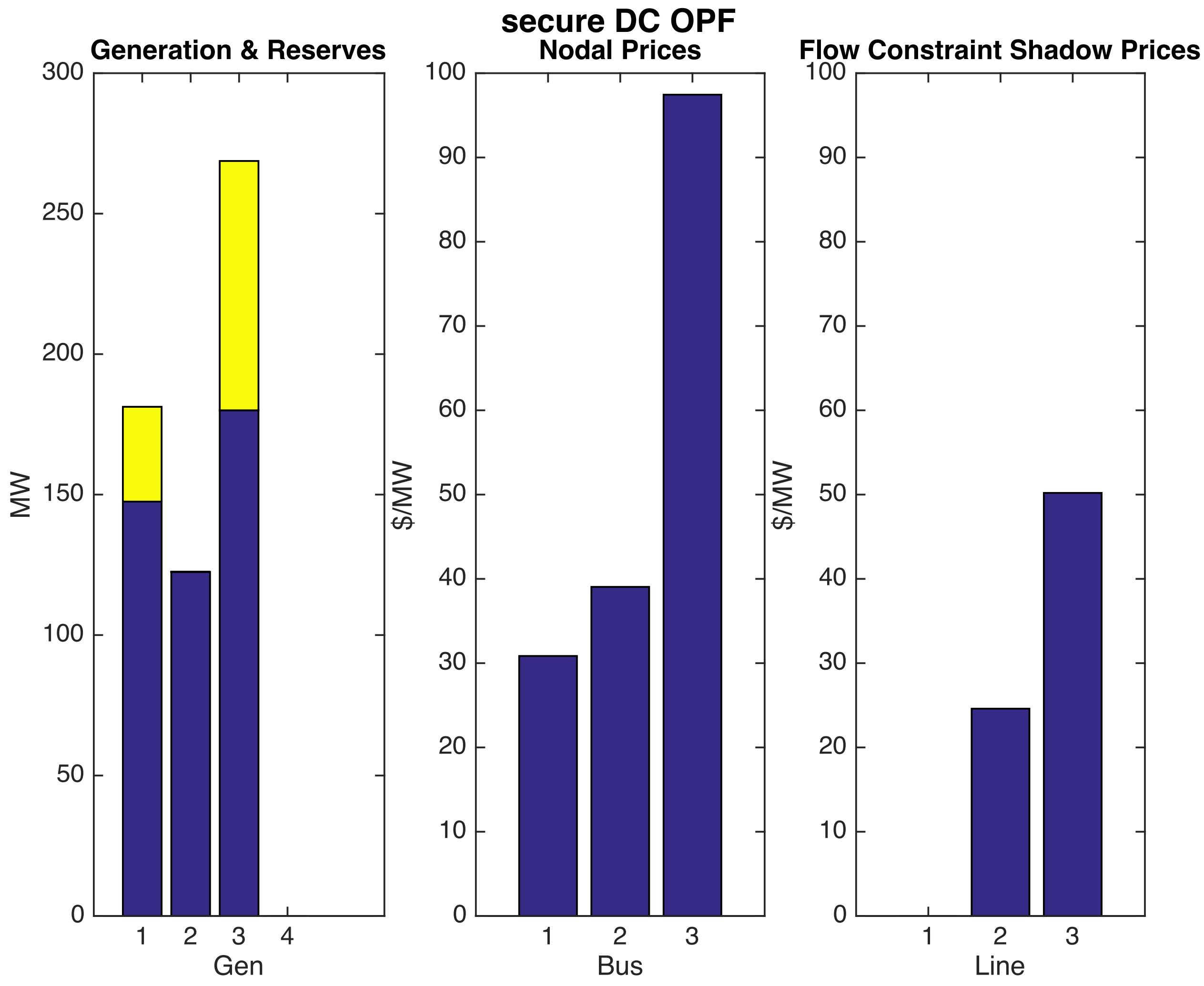
Single Period Continuous Examples



Single Period Continuous Examples



Single Period Continuous Examples



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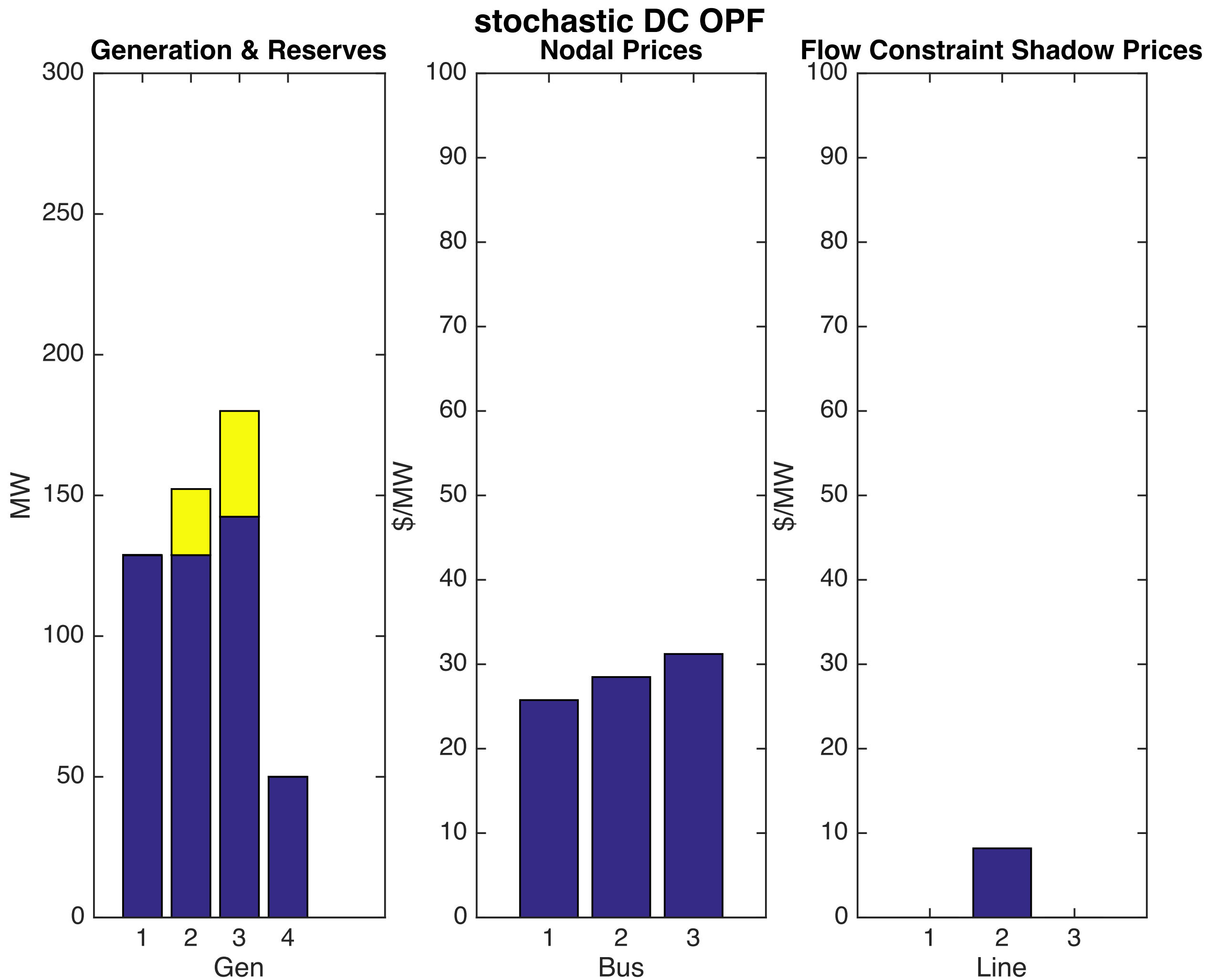
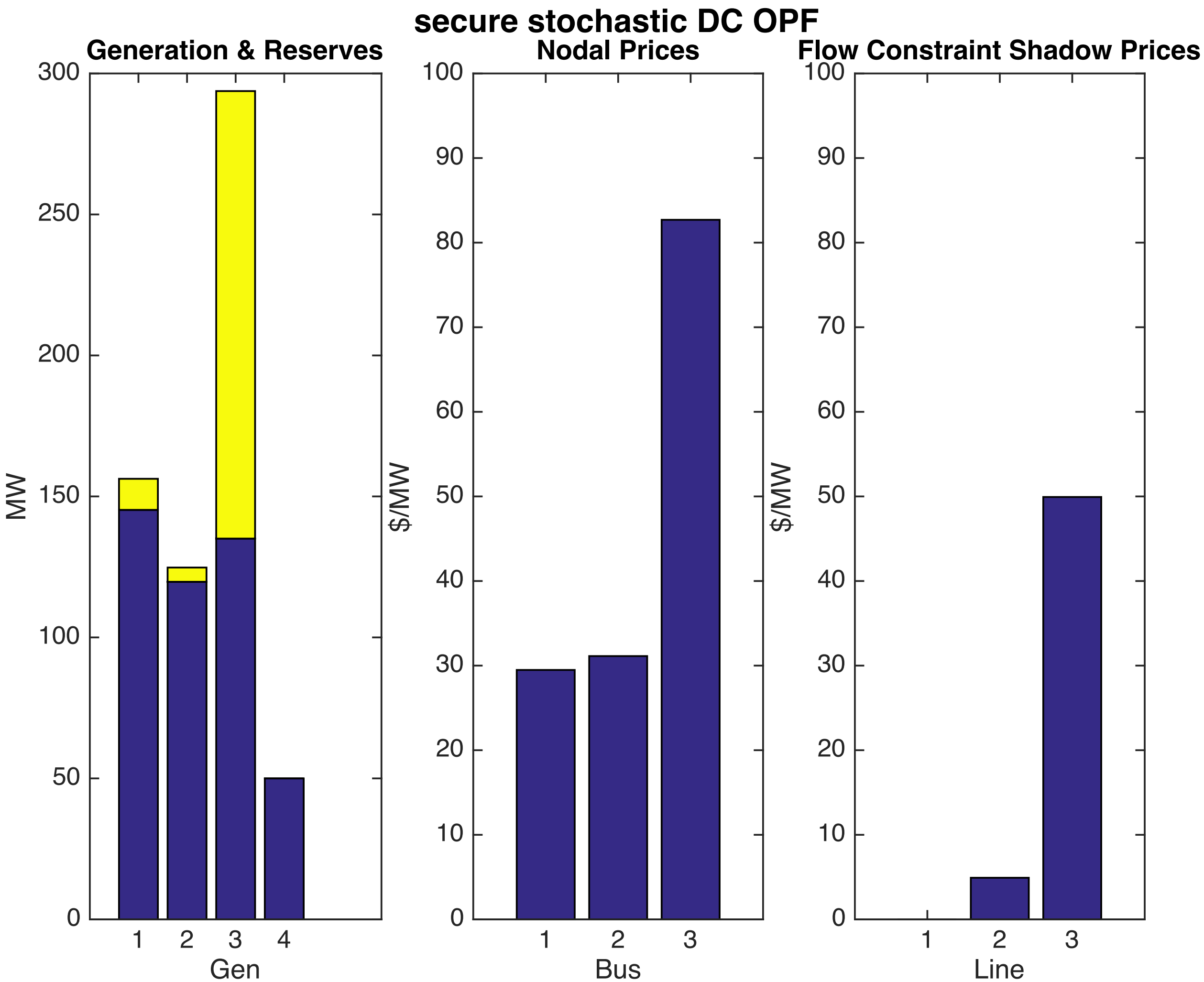
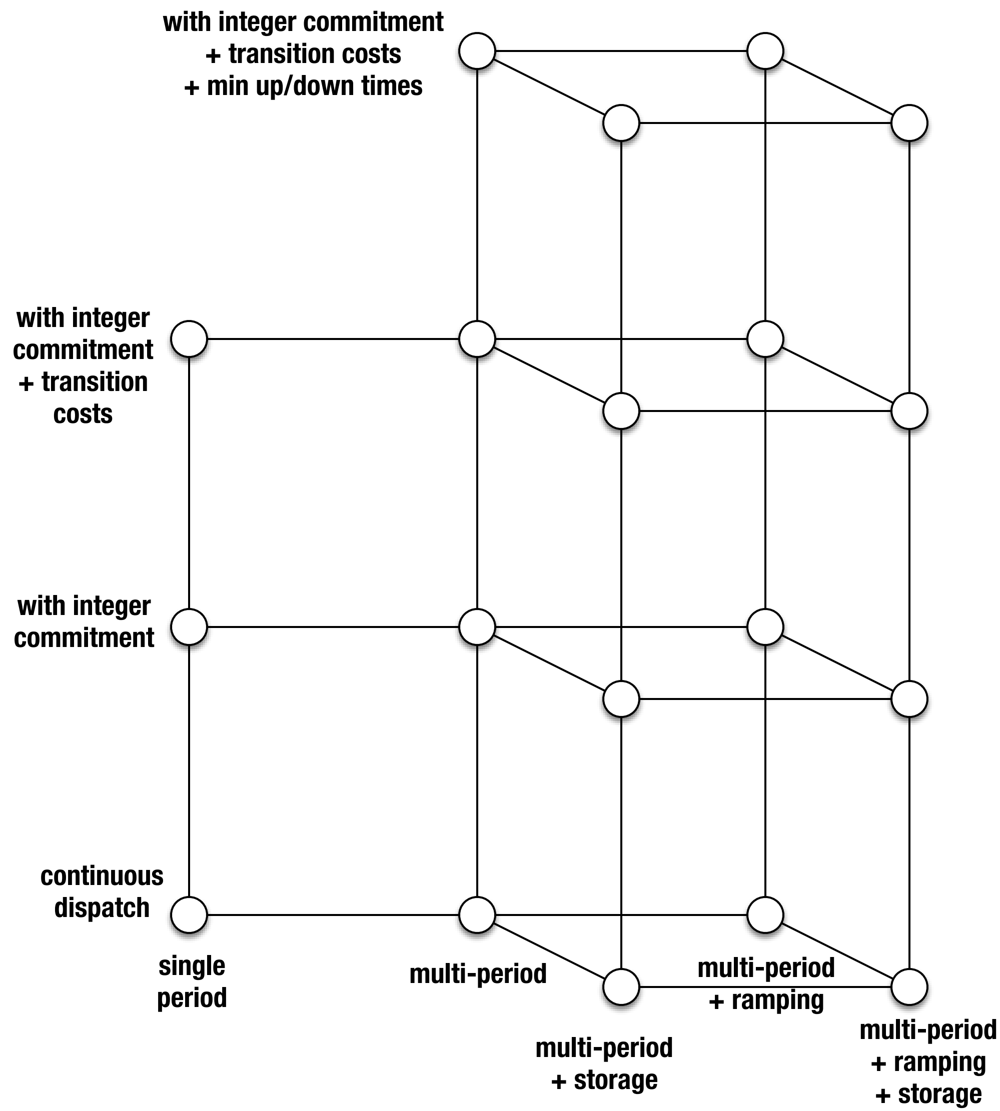


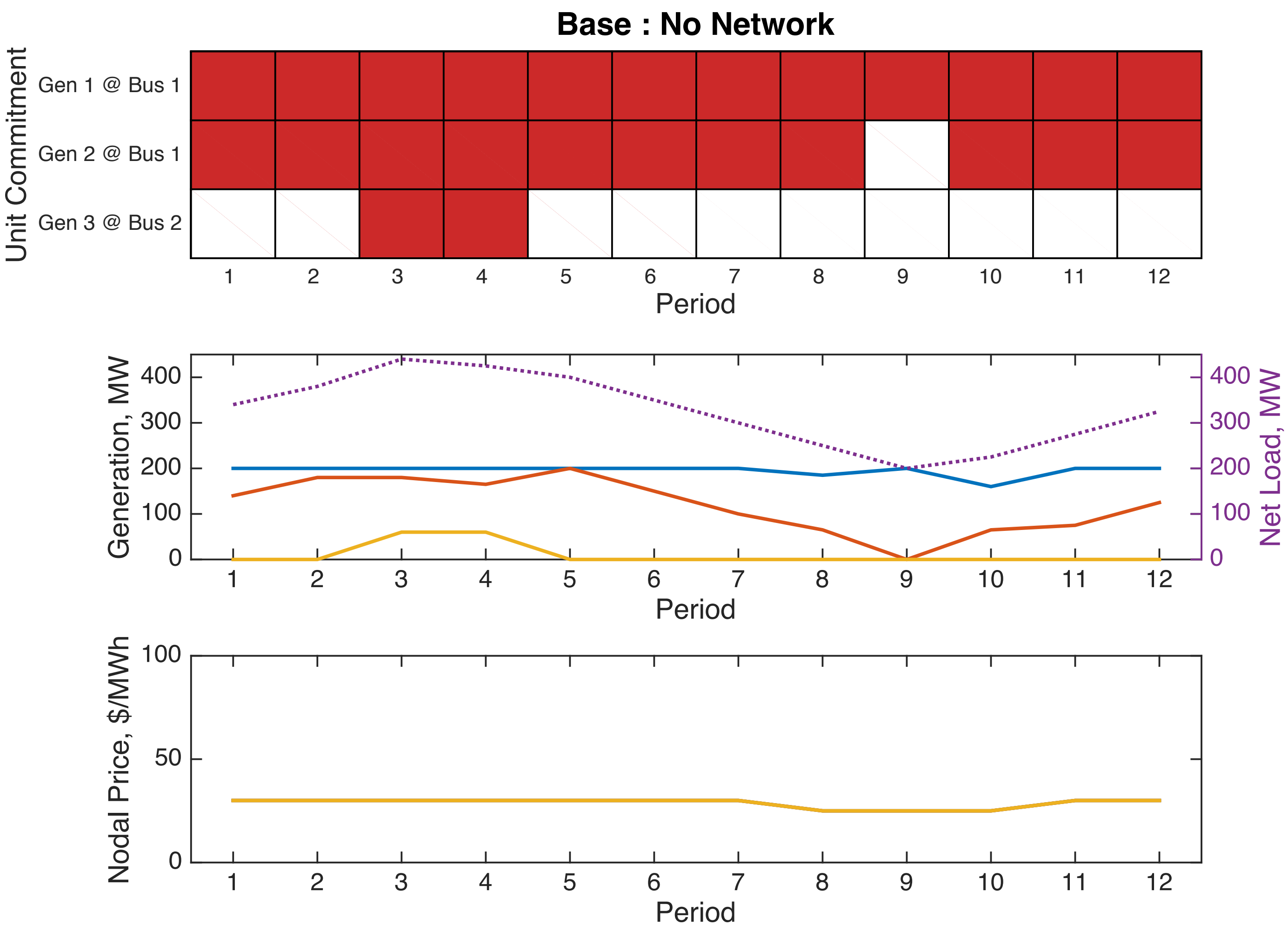
Single Period Continuous Examples



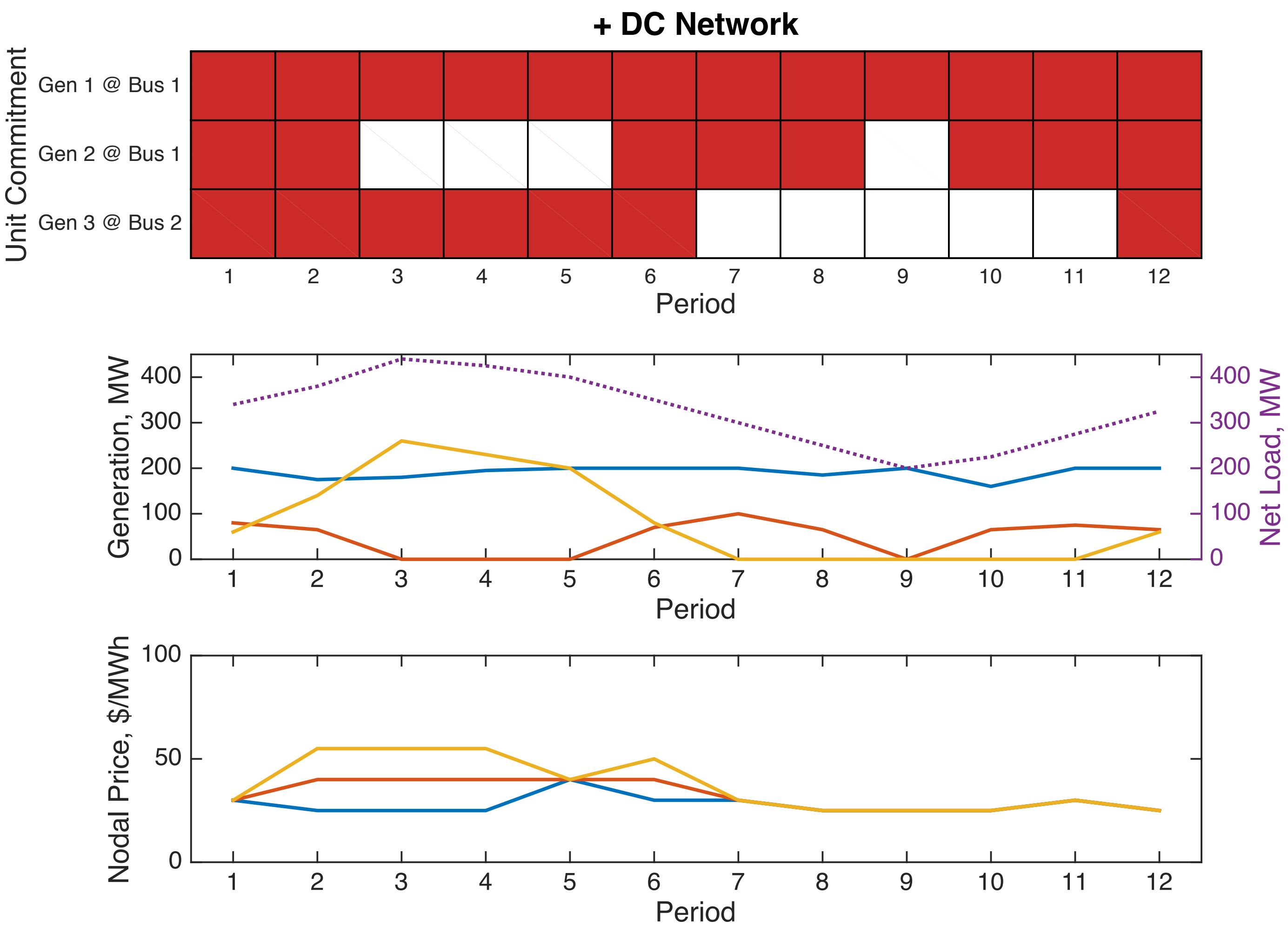
MOPS Mixed Integer and Multi-Period Problems



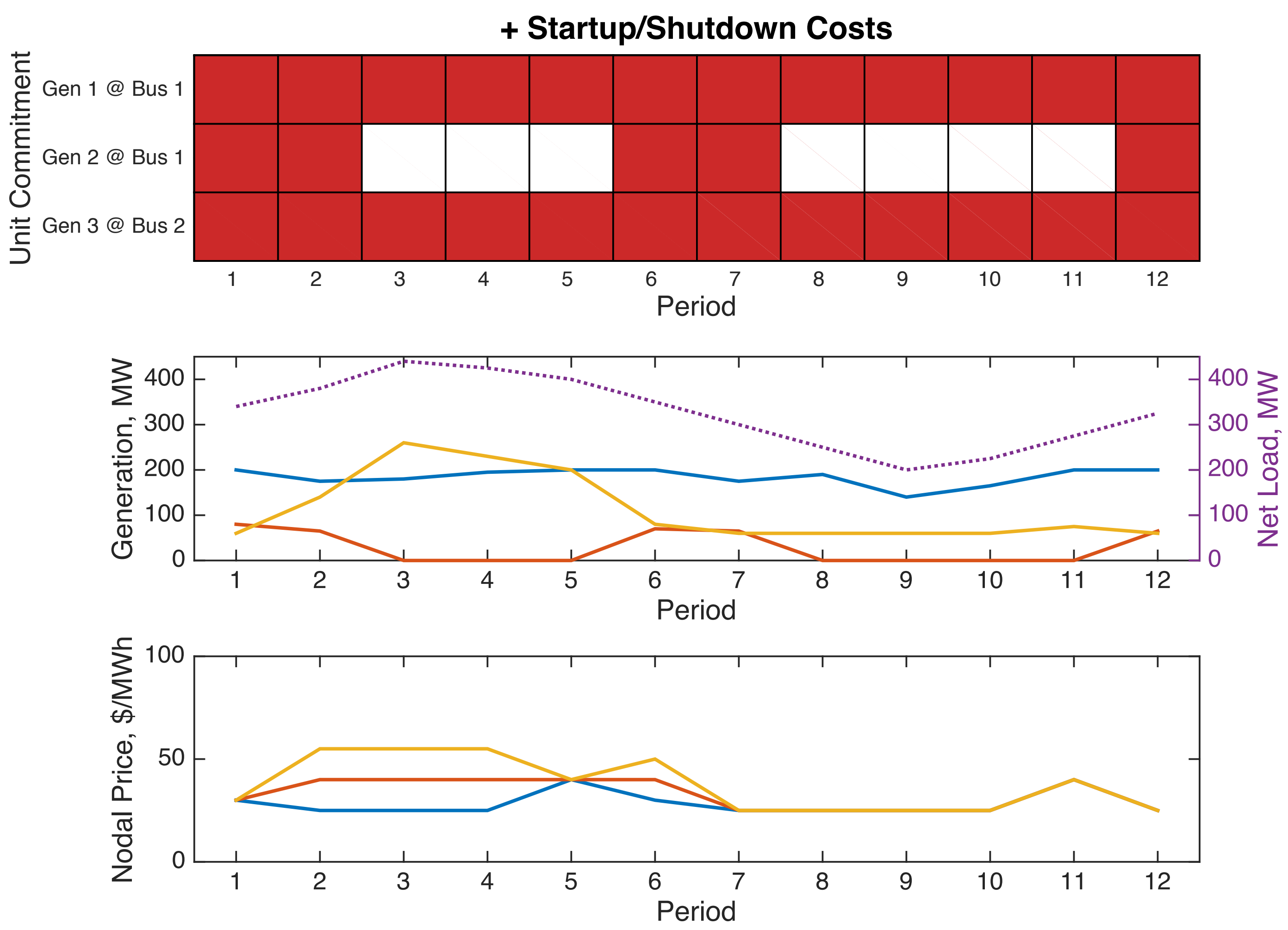
Unit Commitment Examples



Unit Commitment Examples



Unit Commitment Examples



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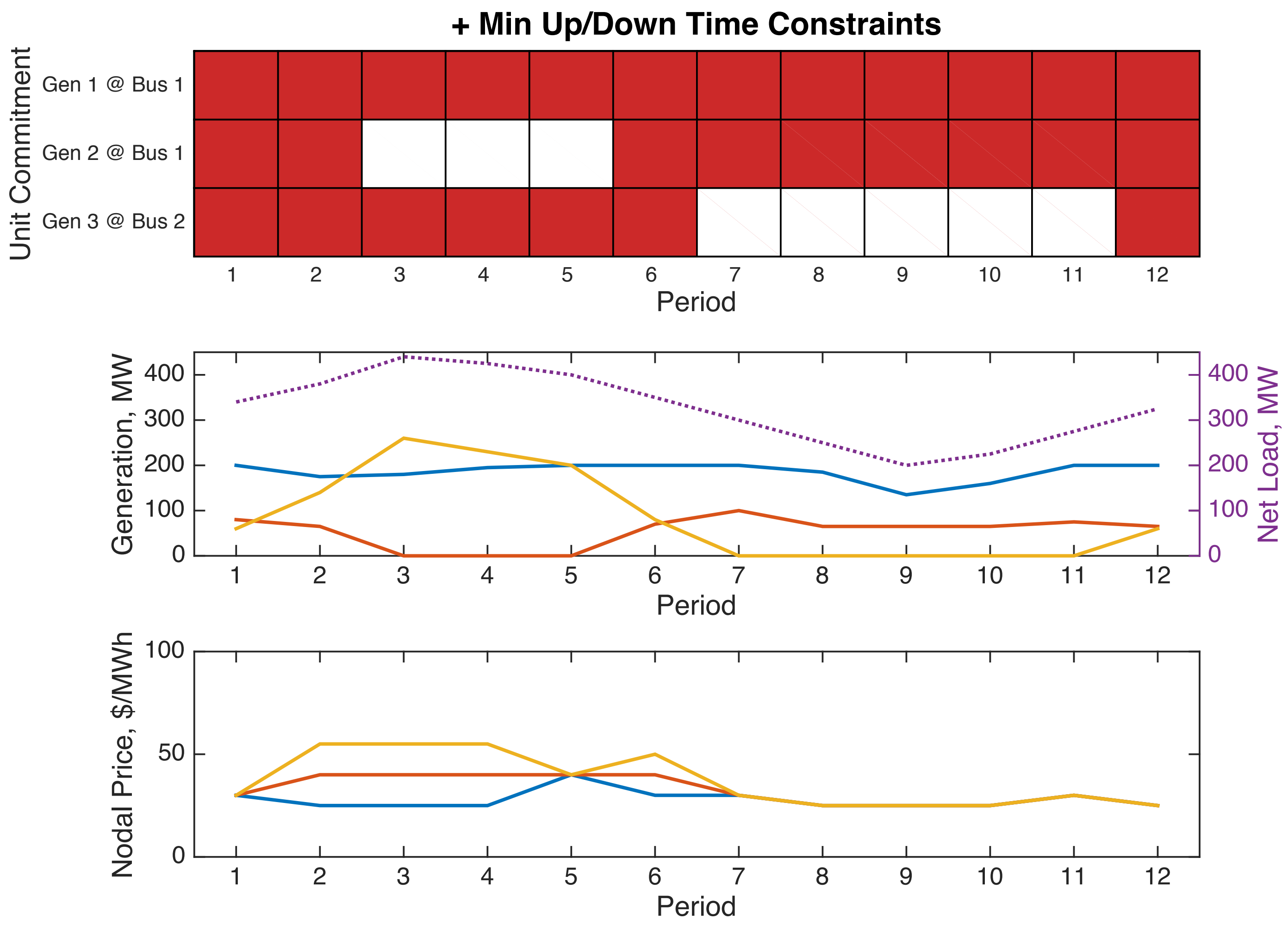
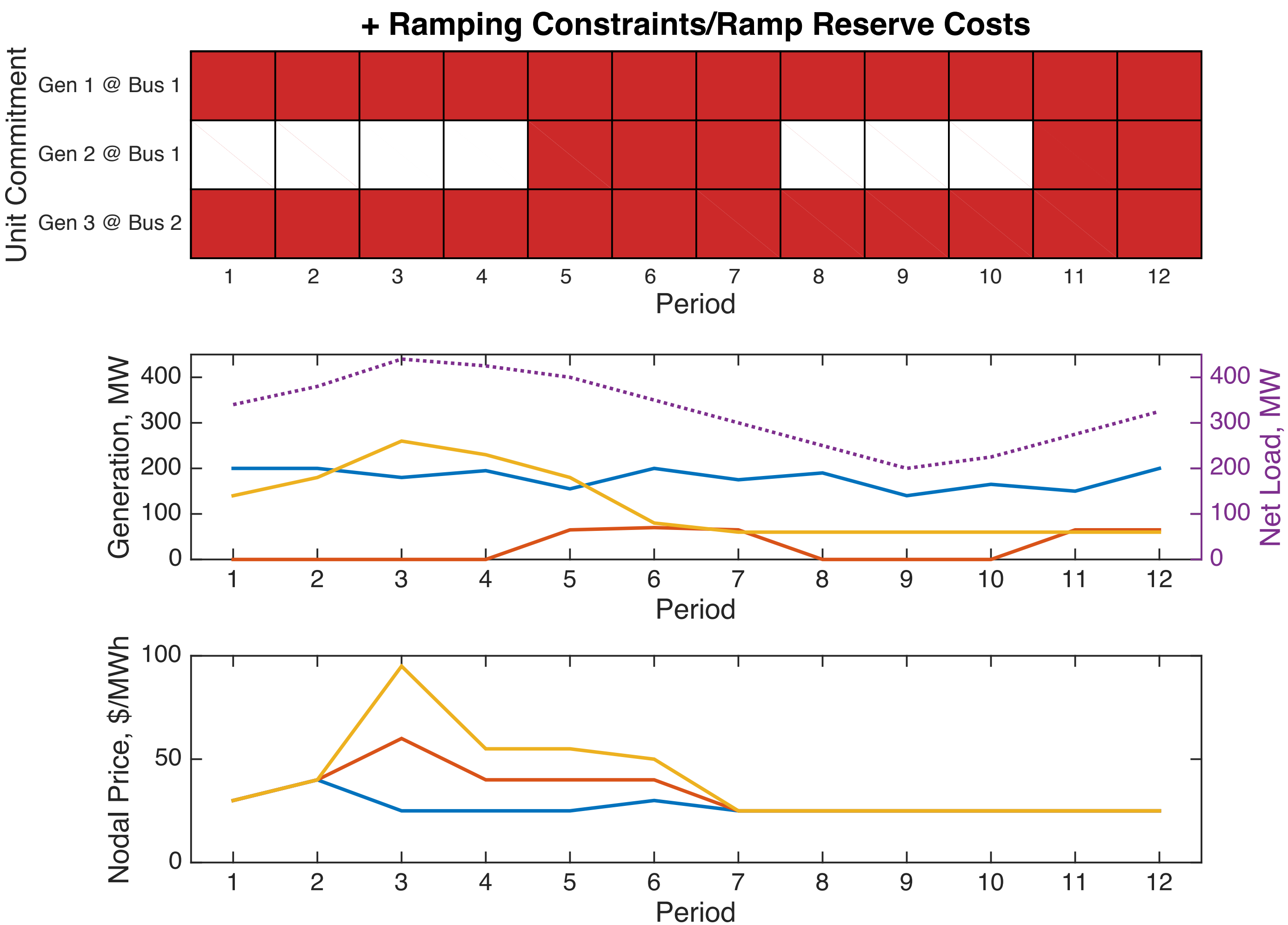


Unit Commitment Examples



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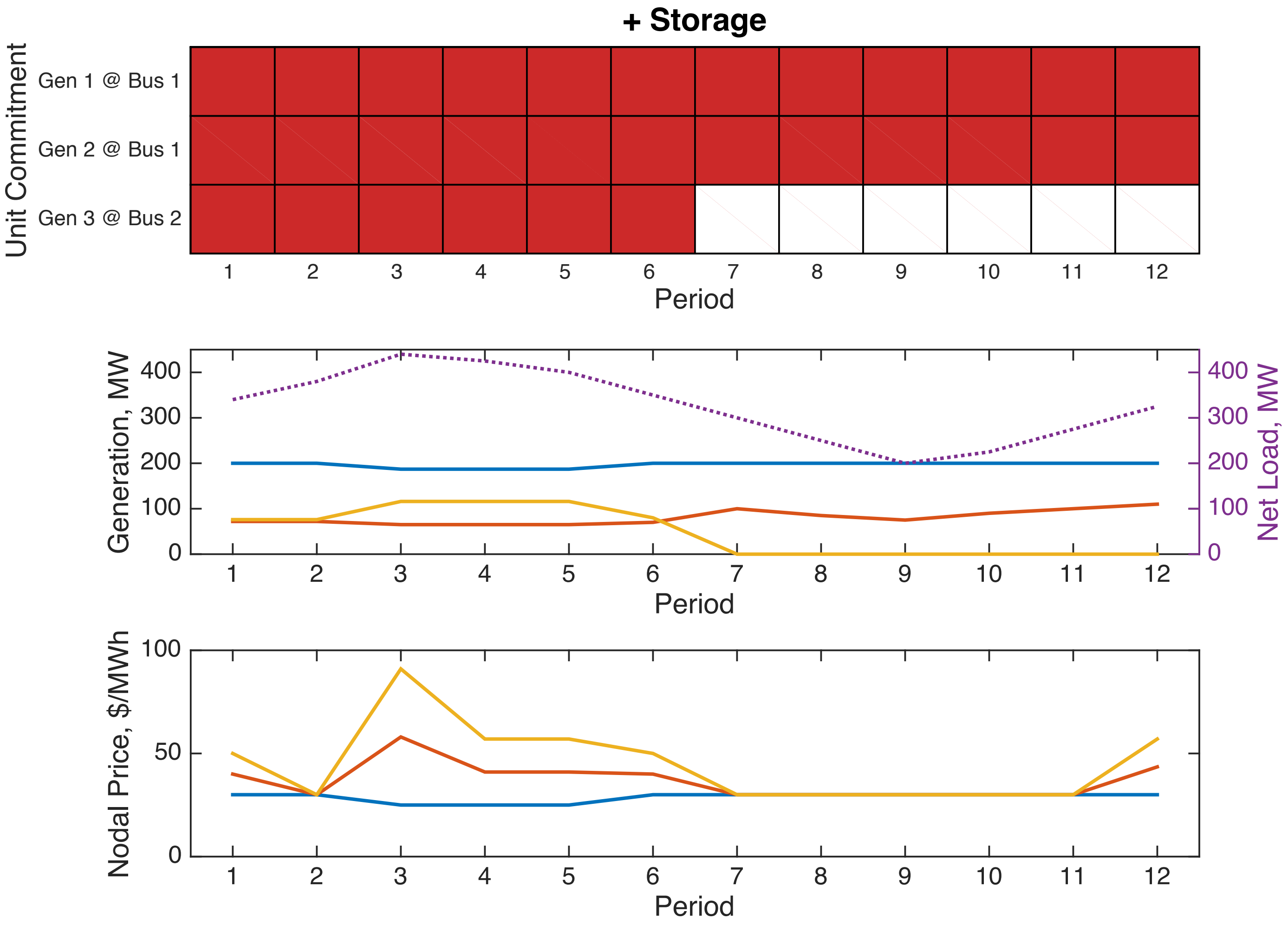

MOPS Status

- Well on way to release in MATPOWER 6.0
  - Need several more months to finalize code cleanup and documentation
- Beyond first public release
  - modifications for probabilistic starting point, required by receding horizon
  - implement fix for stochastic cost distortion related to interaction between commitment status and contingency outages
  - continued work on convergence of AC prototype

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Testing and Simulation Framework

Simulation Environment

defines time structure, data/information flow patterns between …

- *multiple decision stages (e.g. day-ahead UC, 5-min dispatch/pricing)*
- *sequential solves of a given stage*
- *actual operation*

modeling
devices, networks, storage, uncertainty, markets

data

solvers

problem formulation

algorithms

Testing MOPS

- MOPS is a general purpose optimization tool
  - like an OPF
  - can be used in many contexts
- To test MOPS, we need to define a context
  - create a plan given a model of forecasted uncertainty
  - update/execute that plan as uncertainty is revealed through time
  - measure performance (e.g. cost, other metrics)
  - Monte Carlo comparisons
- Questions
  - How to execute the plan?
    - what is locked in, what's free to change?
  - Operating policy vs. market design?

Testing MOPS

Stochastic

Secure UC+OPF

- multiple scenarios for demand and renewable availability
- explicit contingencies for security

Deterministic

UC+OPF

- single scenario with expected demand and renewable availability
- zonal reserve requirements for security

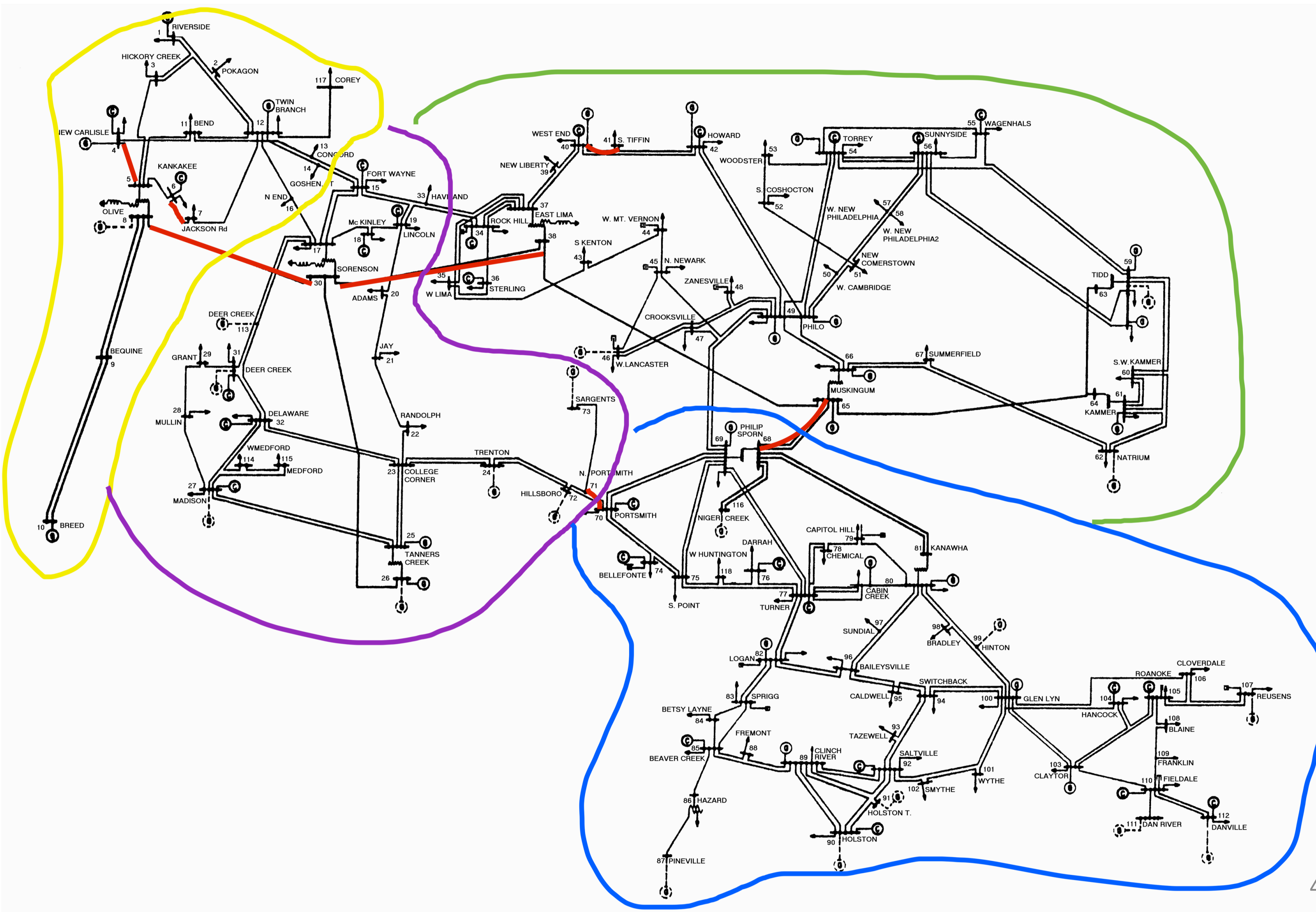
Two Settlement Framework

- 1st settlement
  - solves a multi-period plan resulting in day-ahead commitment decisions and reserve allocations
- 2nd settlement
  - solves single-period problem to determine energy dispatch and contingency reserve allocation subject to
    - UC decisions from 1st settlement
    - dispatch from previous period 2nd settlement
    - newly revealed uncertainty
  - currently using 2nd settlement to approximate actual operation

Testing Structure

- Given:
  - historical temp, wind, demand up to operating day *(any selected day of interest)*
  - ARIMA model of temp, wind, demand that can generate potential realizations of the operating day
- For each approach:
  1. Solve 1st settlement problem for the day (based on uncertainty predicted by the ARIMA model).
  2. Select *N* realizations of the day generated by ARIMA model, for each solve 2nd settlement problems sequentially for each hour, subject to 1st settlement.

118-bus Test System

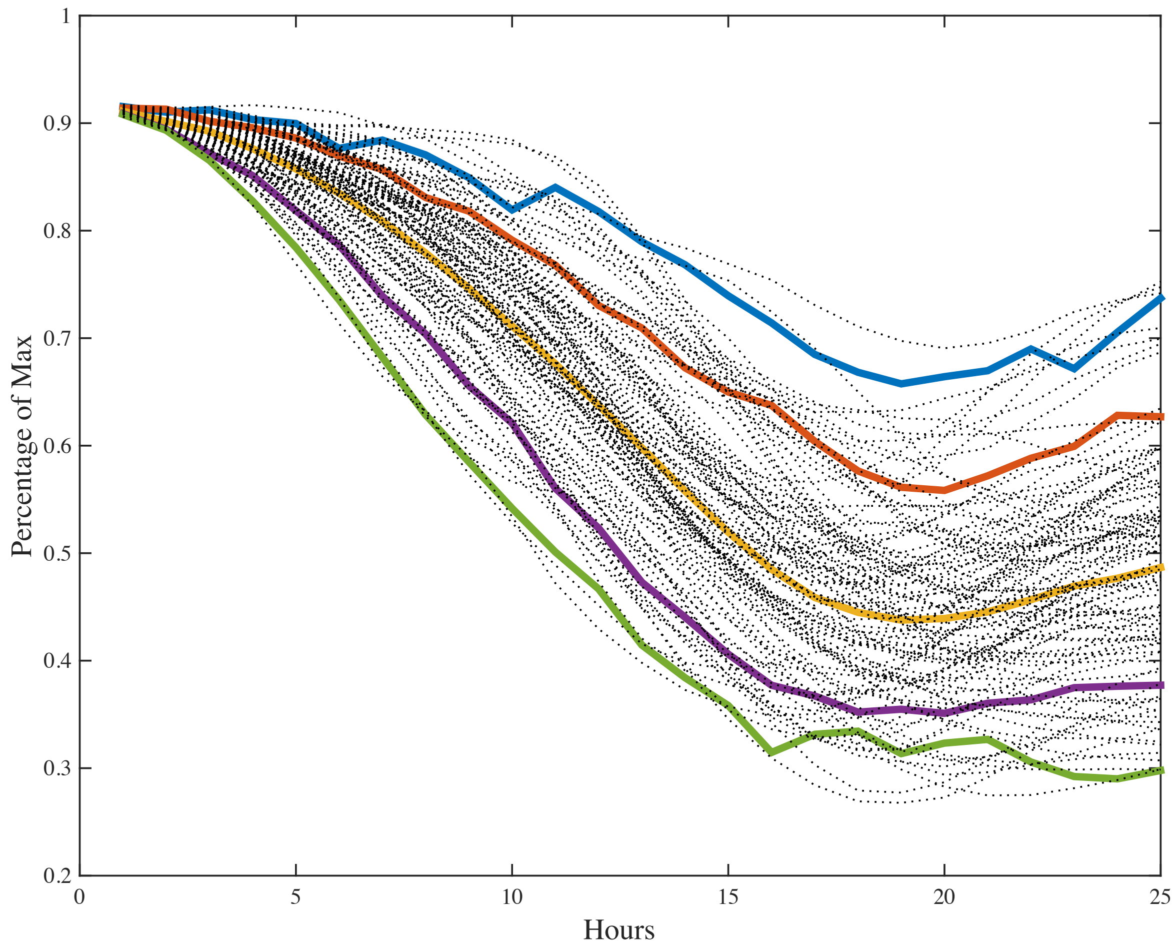


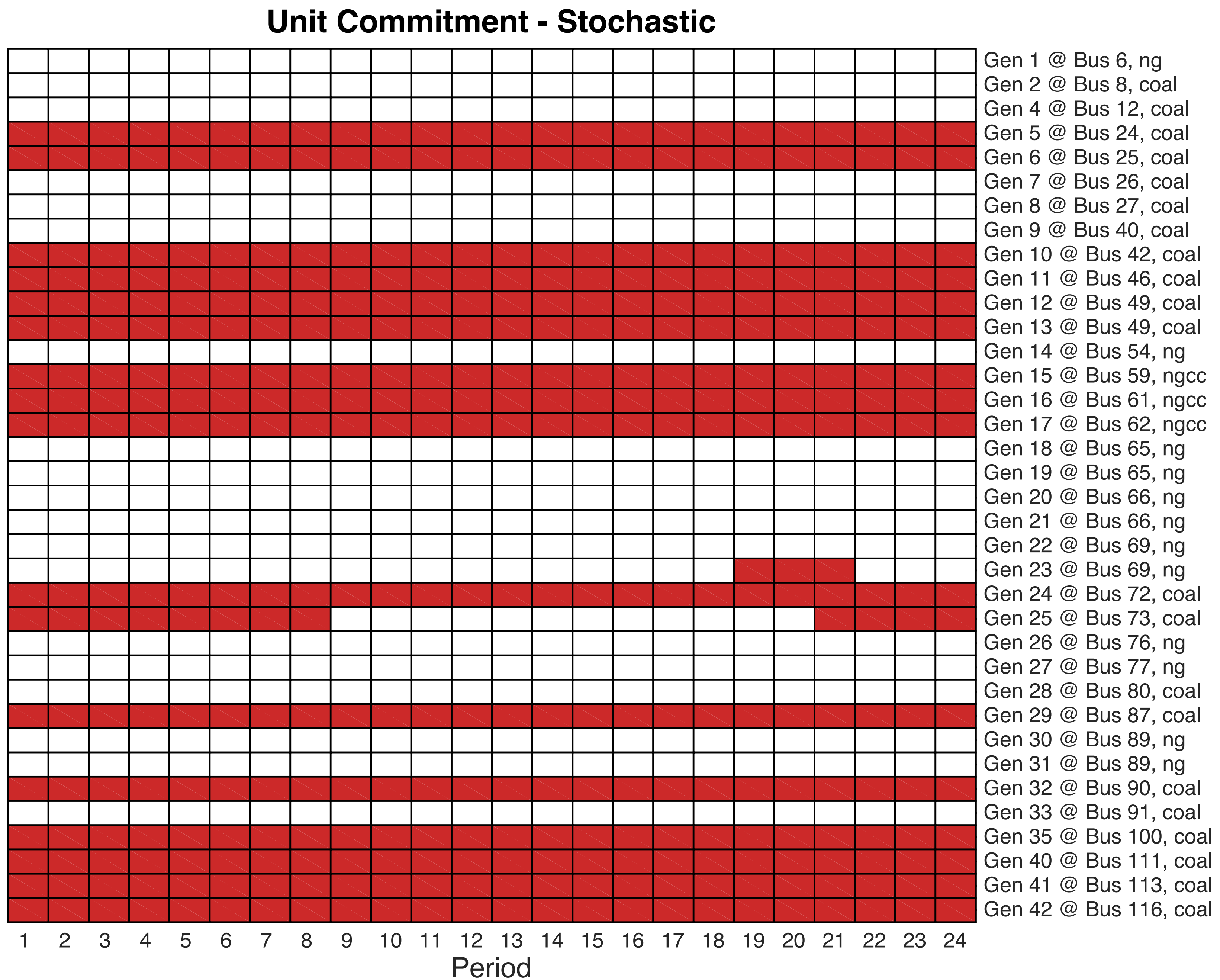
DC Network Example

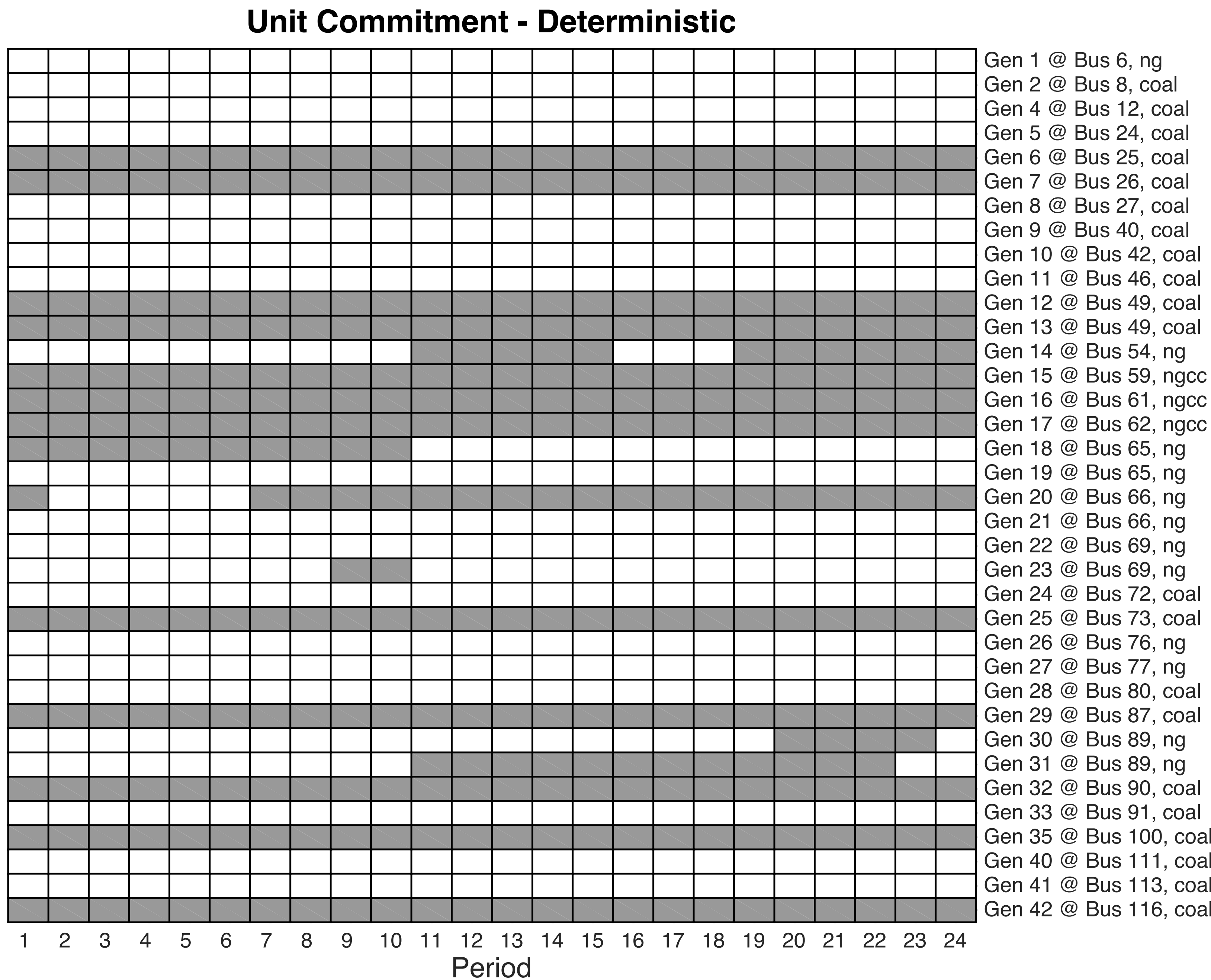
number of ...	
buses	118
conventional generators	42
wind farms	12
grid-level storage units	0
curtailable loads	99
periods in horizon, $\lvert T \rvert$	24
scenarios per period, $\lvert J^t \rvert$	5
contingencies per scenario, $\lvert K^{tj} \rvert - 1$	7
variables in resulting MIQP	582,990
constraints in resulting MIQP	1,536,006

Typical Wind Trajectories

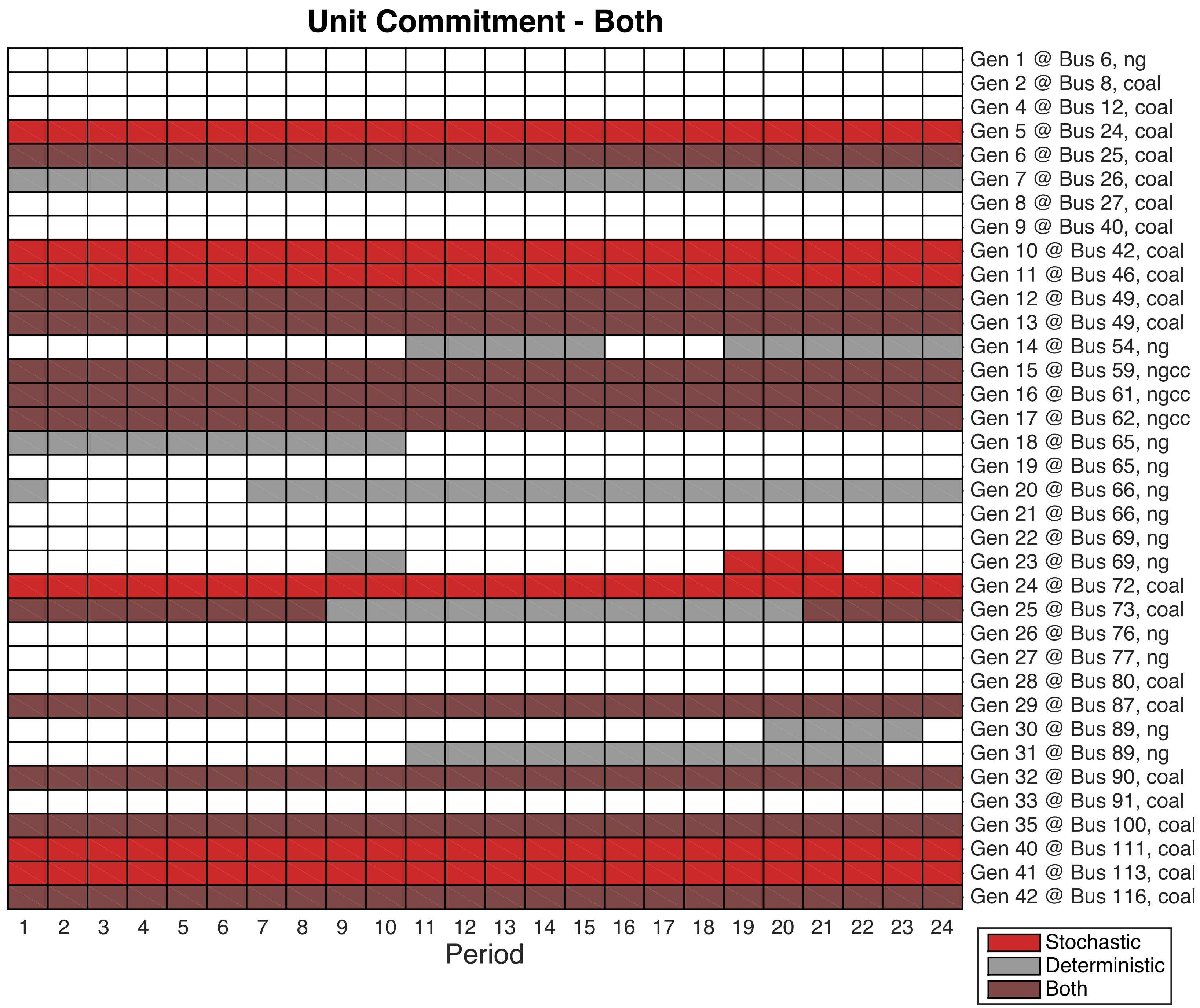
Site 3

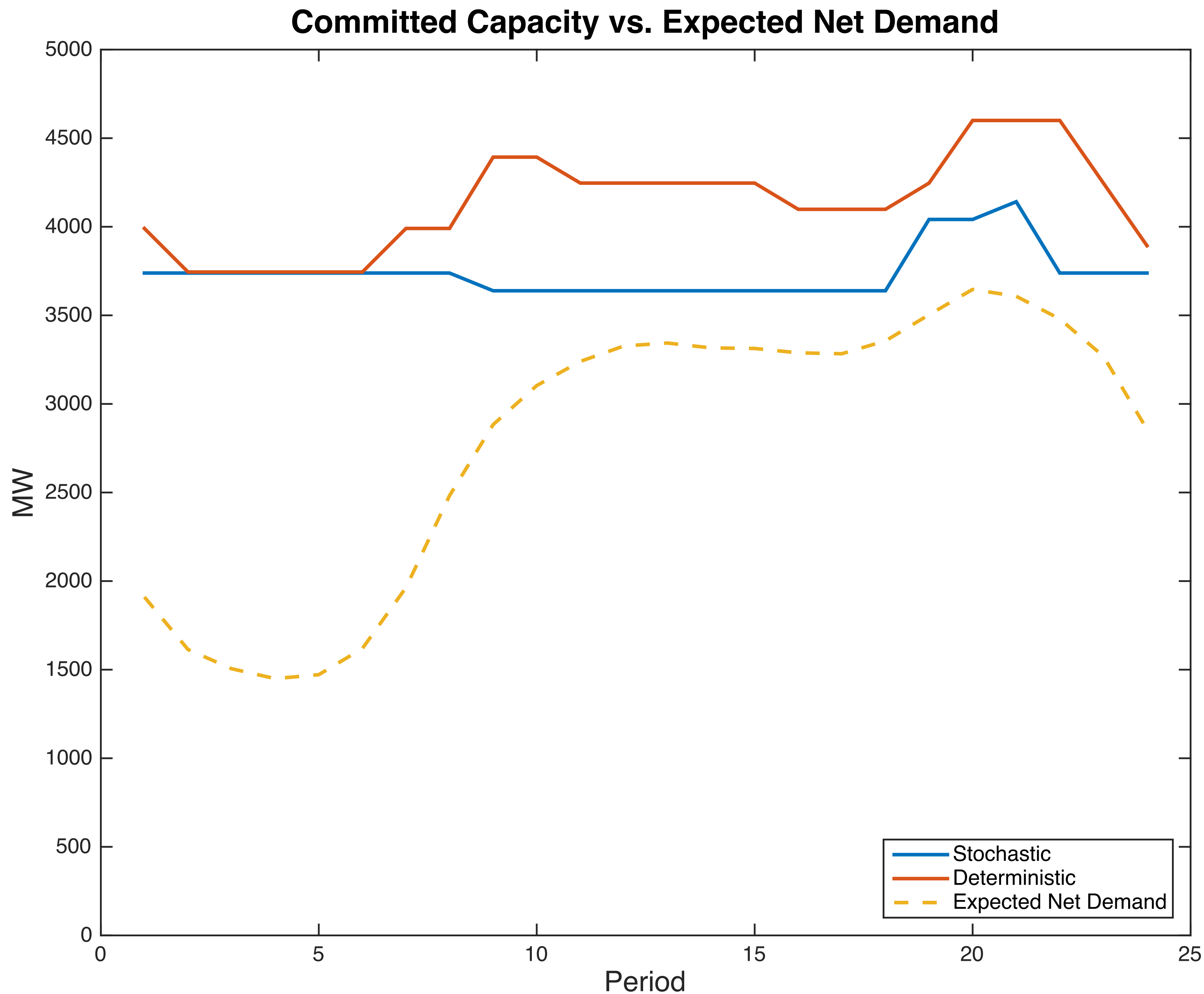



Unit Commitment - Stochastic
Gen 1 @ Bus 6, ng
Gen 2 @ Bus 8, coal
Gen 4 @ Bus 12, coal
Gen 5 @ Bus 24, coal
Gen 6 @ Bus 25, coal
Gen 7 @ Bus 26, coal
Gen 8 @ Bus 27, coal
Gen 9 @ Bus 40, coal
Gen 10 @ Bus 42, coal
Gen 11 @ Bus 46, coal
Gen 12 @ Bus 49, coal
Gen 13 @ Bus 49, coal
Gen 14 @ Bus 54, ng
Gen 15 @ Bus 59, ngcc
Gen 16 @ Bus 61, ngcc
Gen 17 @ Bus 62, ngcc
Gen 18 @ Bus 65, ng
Gen 19 @ Bus 65, ng
Gen 20 @ Bus 66, ng
Gen 21 @ Bus 66, ng
Gen 22 @ Bus 69, ng
Gen 23 @ Bus 69, ng
Gen 24 @ Bus 72, coal
Gen 25 @ Bus 73, coal
Gen 26 @ Bus 76, ng
Gen 27 @ Bus 77, ng
Gen 28 @ Bus 80, coal
Gen 29 @ Bus 87, coal
Gen 30 @ Bus 89, ng
Gen 31 @ Bus 89, ng
Gen 32 @ Bus 90, coal
Gen 33 @ Bus 91, coal
Gen 35 @ Bus 100, coal
Gen 40 @ Bus 111, coal
Gen 41 @ Bus 113, coal
Gen 42 @ Bus 116, coal
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Period

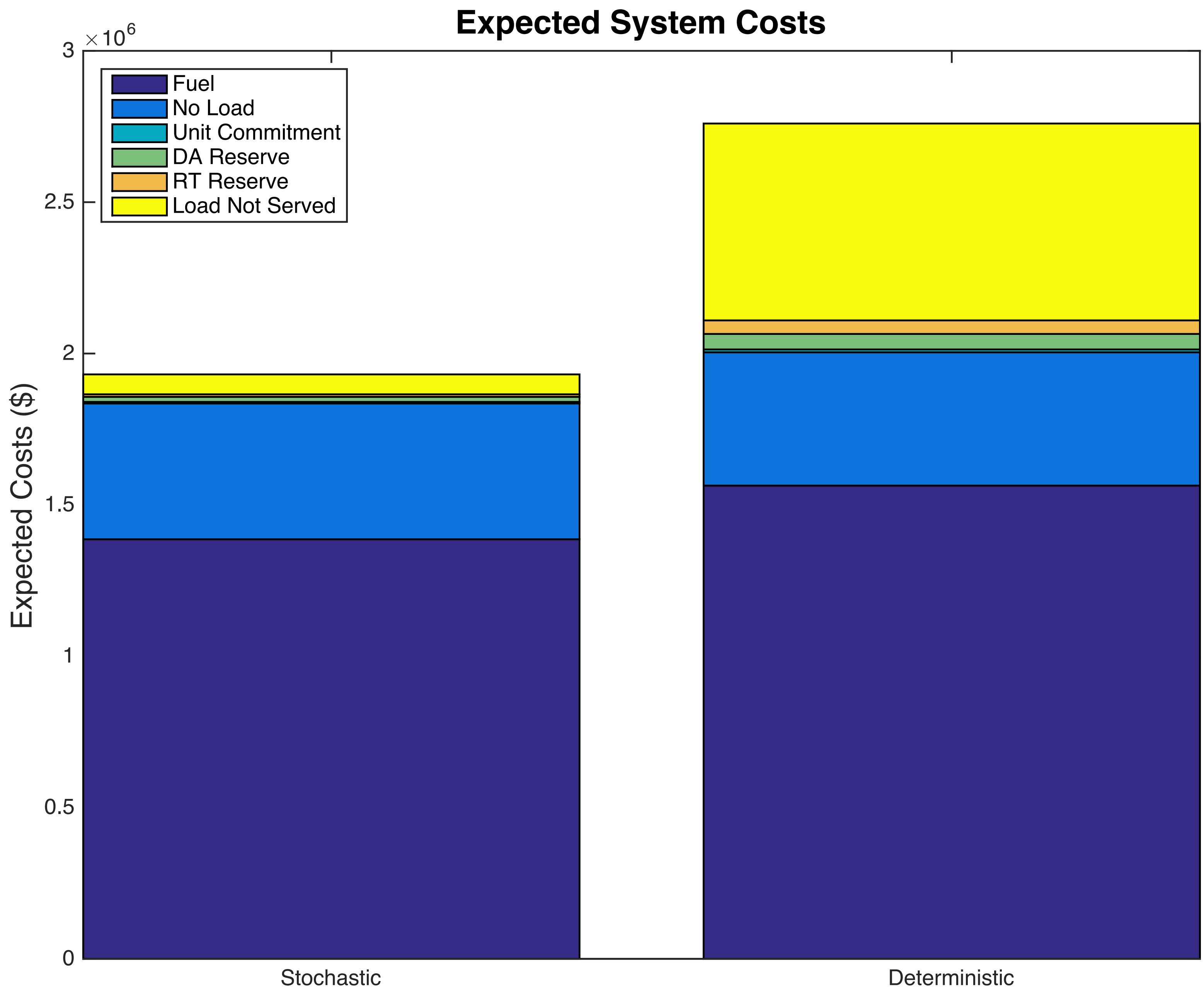


Unit Commitment - Deterministic
Gen 1 @ Bus 6, ng
Gen 2 @ Bus 8, coal
Gen 4 @ Bus 12, coal
Gen 5 @ Bus 24, coal
Gen 6 @ Bus 25, coal
Gen 7 @ Bus 26, coal
Gen 8 @ Bus 27, coal
Gen 9 @ Bus 40, coal
Gen 10 @ Bus 42, coal
Gen 11 @ Bus 46, coal
Gen 12 @ Bus 49, coal
Gen 13 @ Bus 49, coal
Gen 14 @ Bus 54, ng
Gen 15 @ Bus 59, ngcc
Gen 16 @ Bus 61, ngcc
Gen 17 @ Bus 62, ngcc
Gen 18 @ Bus 65, ng
Gen 19 @ Bus 65, ng
Gen 20 @ Bus 66, ng
Gen 21 @ Bus 66, ng
Gen 22 @ Bus 69, ng
Gen 23 @ Bus 69, ng
Gen 24 @ Bus 72, coal
Gen 25 @ Bus 73, coal
Gen 26 @ Bus 76, ng
Gen 27 @ Bus 77, ng
Gen 28 @ Bus 80, coal
Gen 29 @ Bus 87, coal
Gen 30 @ Bus 89, ng
Gen 31 @ Bus 89, ng
Gen 32 @ Bus 90, coal
Gen 33 @ Bus 91, coal
Gen 35 @ Bus 100, coal
Gen 40 @ Bus 111, coal
Gen 41 @ Bus 113, coal
Gen 42 @ Bus 116, coal
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Period


Unit Commitment - Both
Gen 1 @ Bus 6, ng
Gen 2 @ Bus 8, coal
Gen 4 @ Bus 12, coal
Gen 5 @ Bus 24, coal
Gen 6 @ Bus 25, coal
Gen 7 @ Bus 26, coal
Gen 8 @ Bus 27, coal
Gen 9 @ Bus 40, coal
Gen 10 @ Bus 42, coal
Gen 11 @ Bus 46, coal
Gen 12 @ Bus 49, coal
Gen 13 @ Bus 49, coal
Gen 14 @ Bus 54, ng
Gen 15 @ Bus 59, ngcc
Gen 16 @ Bus 61, ngcc
Gen 17 @ Bus 62, ngcc
Gen 18 @ Bus 65, ng
Gen 19 @ Bus 65, ng
Gen 20 @ Bus 66, ng
Gen 21 @ Bus 66, ng
Gen 22 @ Bus 69, ng
Gen 23 @ Bus 69, ng
Gen 24 @ Bus 72, coal
Gen 25 @ Bus 73, coal
Gen 26 @ Bus 76, ng
Gen 27 @ Bus 77, ng
Gen 28 @ Bus 80, coal
Gen 29 @ Bus 87, coal
Gen 30 @ Bus 89, ng
Gen 31 @ Bus 89, ng
Gen 32 @ Bus 90, coal
Gen 33 @ Bus 91, coal
Gen 35 @ Bus 100, coal
Gen 40 @ Bus 111, coal
Gen 41 @ Bus 113, coal
Gen 42 @ Bus 116, coal
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24
Period
Stochastic
Deterministic
Both

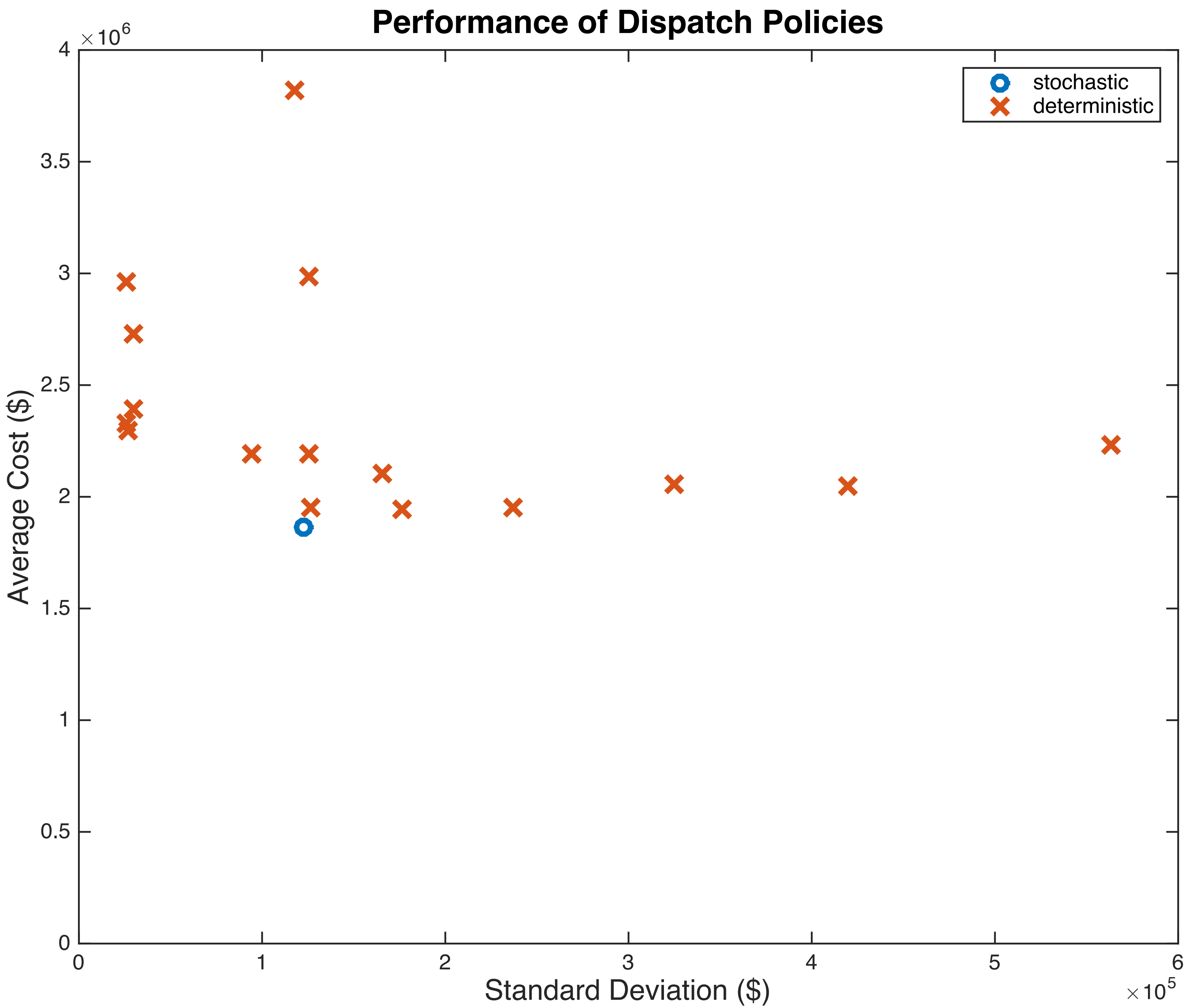


Committed Capacity vs. Expected Net Demand
MW
Period
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
0
5
10
15
20
25
Stochastic
Deterministic
Expected Net Demand


Expected System Costs
×10^6
3
2.5
2
1.5
1
0.5
0
Expected Costs ($)
Fuel
No Load
Unit Commitment
DA Reserve
RT Reserve
Load Not Served
Stochastic
Deterministic

Expected Cost Comparison

	Stochastic	Deterministic	Difference
fuel	$1,386,000	$1,564,000	9%
no load	$449,000	$440,000	0%
UC	$5,000	$9,000	0%
DA Reserve	$17,000	$51,000	2%
RT Reserve	$8,000	$45,000	2%
LNS	$66,000	$650,000	30%
Total	$1,931,000	$2,760,000	43%



Performance of Dispatch Policies
stochastic
deterministic
Average Cost ($)
×10^6
4
3.5
3
2.5
2
1.5
1
0.5
0
Standard Deviation ($)
×10^5
0
1
2
3
4
5
6

Two-Settlement Challenges

- Began with the idea that 1st settlement contracts for commitment, energy, reserves and ramping would provide "look-ahead view" to constrain single-period 2nd settlement problem
  - too restrictive
  - resulted in shedding load when unused capacity was available
    - unused capacity hadn't been contracted
  - consequence of
    - myopic (single-period) second settlement problem
    - simplified uncertainty model
- Moved to having second settlement take only UC from first settlement results
  - full range of generator available for dispatch and reserves
  - continue to guard against contingencies
  - ignores first settlement ranges that guarantee ramping feasibility

Question

- How should we use the information from the results of coarser, longer horizon "look-ahead" plan to guide the updating of that plan by a subsequent finer grain, but shorter horizon problem with new information?
  - context of testing environment
  - market design context

Overview

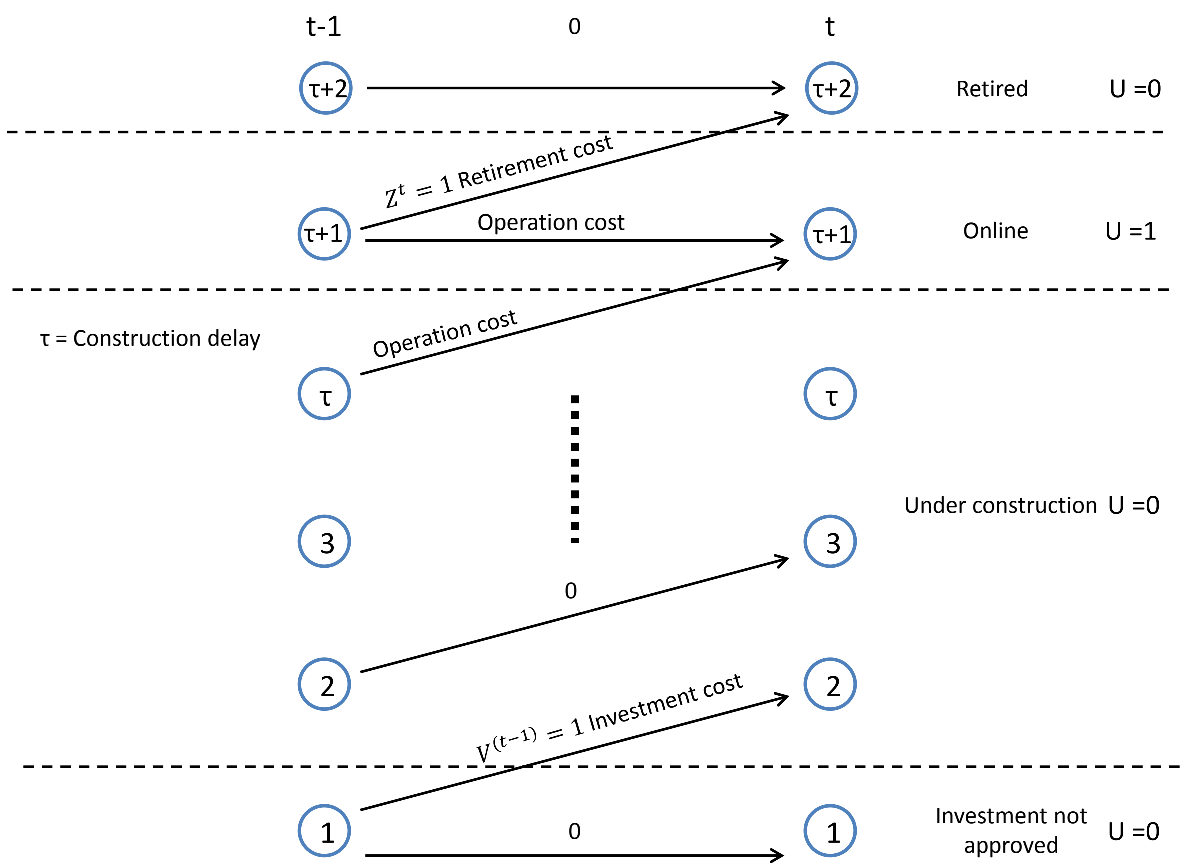
- **Background** – motivation, context, status
- **MATPOWER** – updates and direction
- **MOPS** – MATPOWER Optimal Power Scheduler
- **Testing MOPS** – simulation framework, tests
- New **expansion planning tool**
- **AC convergence** of MOPS

Comparison to Current E4ST

New Formulation	E4ST
AC or DC network model	DC network model only
binary variables for investment/retirement decisions	continuous variables for investment/retirement decisions
single time-linked optimization for entire horizon	independent sequential optimizations
temporally co-optimized investment/retirement decisions	independent sequential investment/retirement decisions
fine time-granularity on investment decisions, yearly steps	coarse time-granularity on investment decisions, decade steps
technology-specific invest-to-deploy delays	uniform invest-to-deploy delay *(granularity of investment cycles)*
explicit zonal operating reserves	availability factors as proxy for operating reserves, etc.
linear elastic zonal fuel supply functions, possibly with delay	exogenous fuel prices
*potential to include ramping and UC via typical trajectories**	operations consists of single independent hours
iterative solution of model decomposition	direct solution of single large model**
highly parallelizable	limited opportunities for parallel computation
approximate solution with small non-zero duality gap	exact solution**
*explicit hydro constraints, etc. not yet implemented**	total output constraints for hydro, emissions, RPS

* future enhancement
** for each independent investment cycle

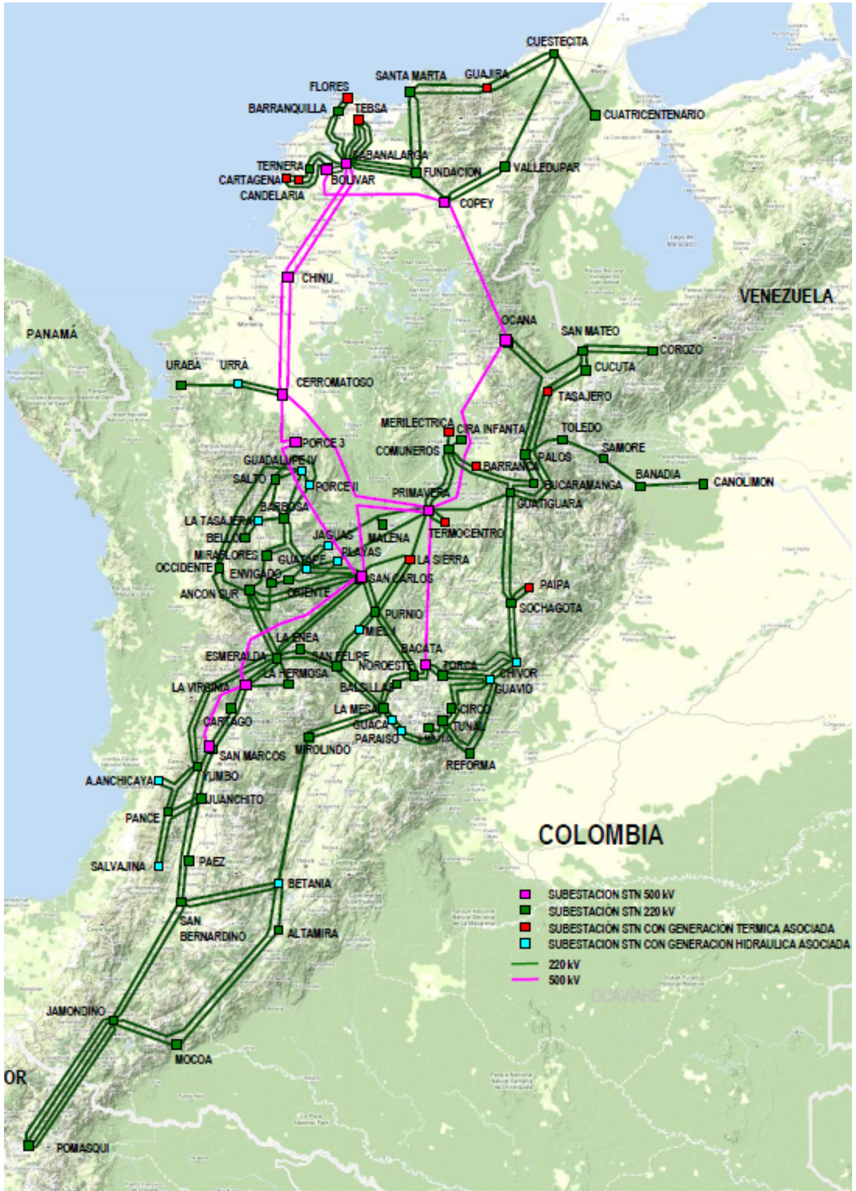
Integer Deployment States

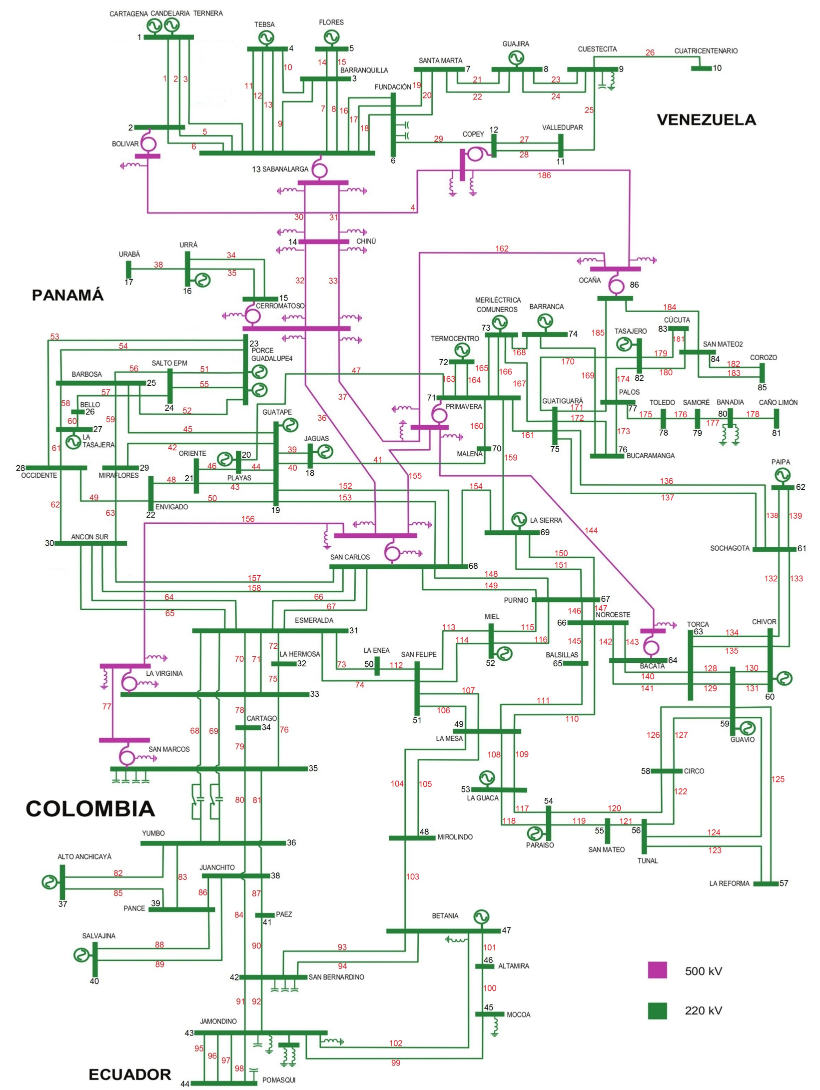


Solution

- Lagrangian relaxation-based coordination and separation of inner minimizations
- Two sets of minimizations
  - independent (AC) OPF problems
    - one per hour type per interval of planning horizon
  - independent dynamic programs
    - one per generator or project
- Highly separable, highly parallelizable
- Potential challenge: LR convergence

Preliminary Test

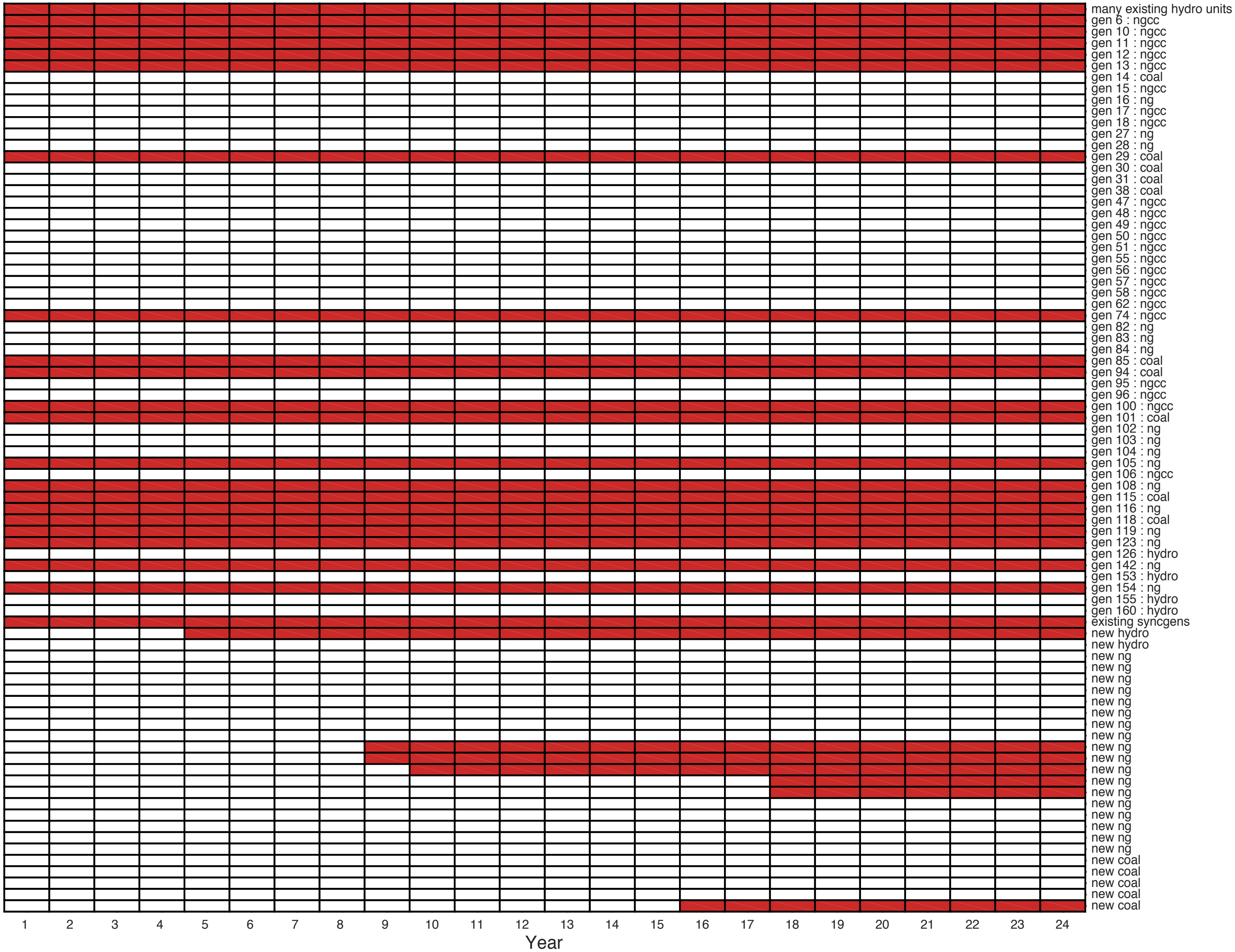




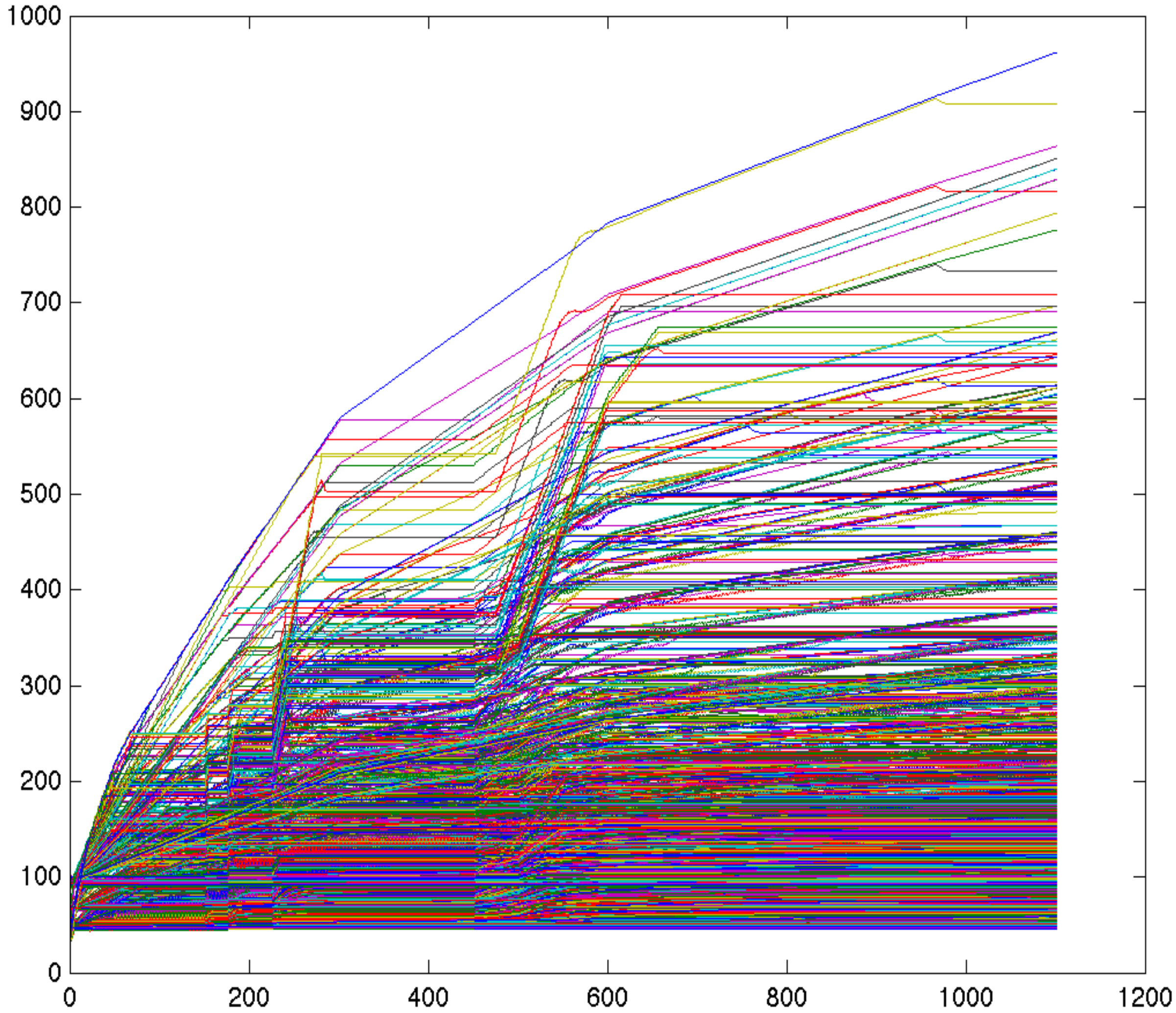
Test Setup

- Colombian system + several additional projects
  - 86 buses
  - 187 existing generation units
- zonal reserve requirement, 5 zones
  - 15% of local demand in each reserve zone
- potential new projects
  - 2 large hydro
  - 18 combined cycle gas
  - 5 large coal
- 5 hour types
- 24 years
- inelastic fuel supply
- 3% yearly discount rate

Online Status of Plants



Dual variables



Preliminary Results

- most dual variables have settled
  - need to explicitly compute duality gap
- new hydro plants and some combined cycle gas units selected for construction
- all natural gas units retired immediately
  - NG is expensive, but units are required to cover hydro shortages during El Niño events
  - requires explicit hydro constraint and possibly explicit modeling of uncertainty to capture properly

Status

- implementation of basic formulation (presented last year) completed
- new elastic linear fuel supply function
  - feature implementation completed
  - generators belong to (possibly overlapping) “fuel zones” in which they compete for fuel in given time horizon/season
- production costs can now include fixed cost proportional to installed capacity of project
- test study for Colombian system is undergoing calibration of model for fuel supply function

To Do

- Add seasonal output restrictions
  - hydro constraints
    - currently requires manually adjusting hydro generation cost
  - emissions caps
  - RPS standards
- Coordinate with current E4ST users to close any other gaps and plan transition
- Future
  - Change scenarios from being “typical hours” to being “typical trajectories” to model ramping requirements
  - Explore ways to include transmission expansion and uncertainty.

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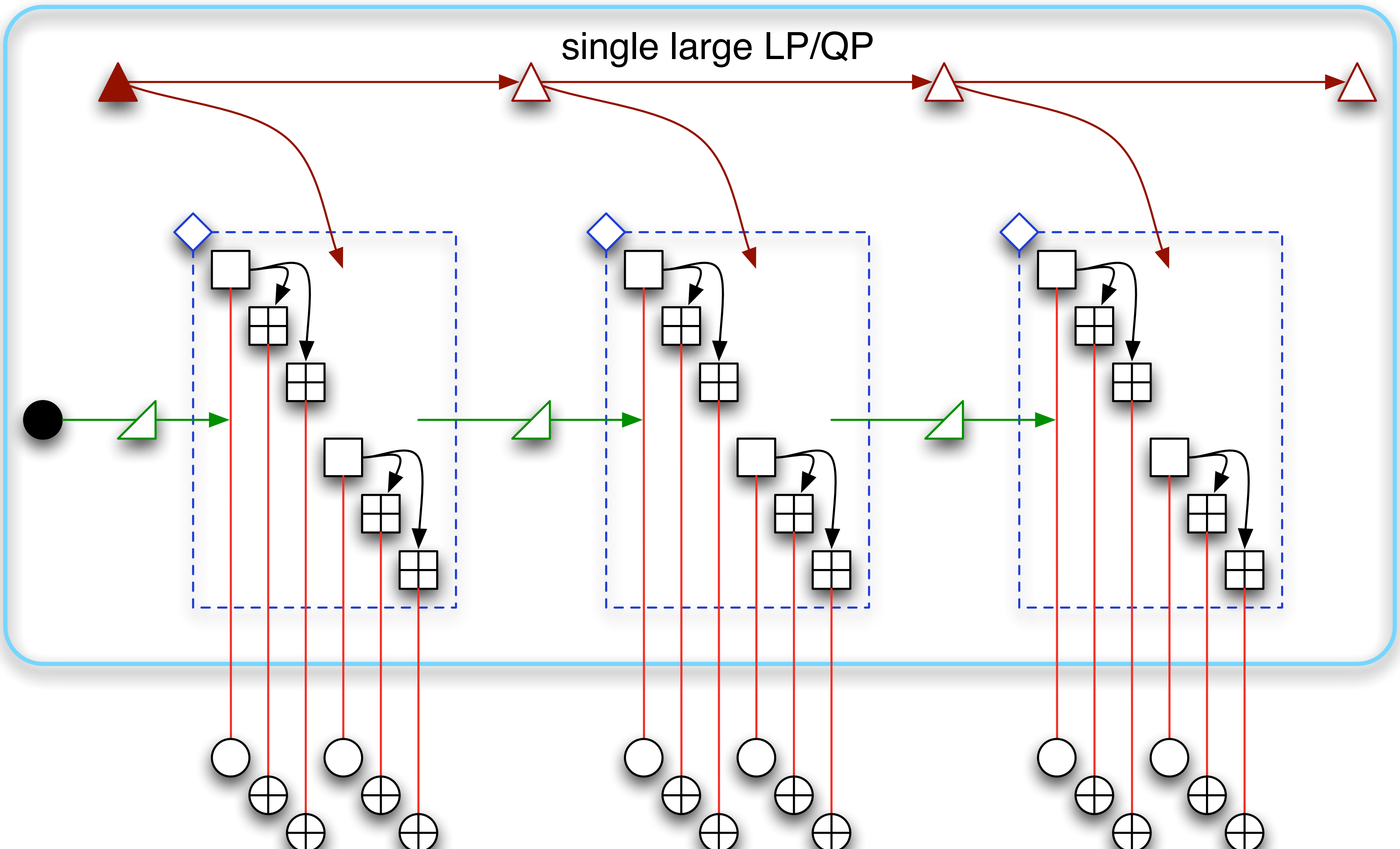
Decomposition of AC MOPS



Convergence of AC MOPS

continuous case

- current LR coordination with subgradient-based lambda update
  - slow and unreliable, especially when some states have negative prices
- improved update strategy to accelerate convergence
  - augment Lagrangian with squares of AC flow equations
    - introduces 2^{nd} order derivatives of injections
  - should improve homing capability of lambda updates

Second Order Update Strategy

- Perform lambda update from sensitivity analysis of FOC of augmented Lagrangian
  - similar to method of multipliers
  - requires solving huge linear system
    - order-of-magnitude speed-ups in solving $Ax = b$ (PARDISO)
    - lambda update based on 2^{nd} order info seems doable scale-wise
- Status
  - under implementation (currently coding Hessians)

Support for Other CERTS Projects

- Bill Schulze – continued E4ST application/ enhancements
- Ben Hobbs – integration with E4ST
- Lindsay Anderson – integration of chance constrained approach with SuperOPF/MOPS
- Zhifang Wang – integration of synthetic power grid modeling capability into MATPOWER
- HyungSeon Oh – AC OPF enhancements
- Kory Hedman – stochastic unit commitment

Summary of FY15

- Complete current **MOPS testing on two-settlement structure** and submit paper to IEEE Transactions.
- Complete **MOPS integration** and release **MATPOWER 6**.
- Submit **NSF grant** to move MATPOWER project to public **open development paradigm** as first step toward sustainable long-term plan for MATPOWER.
- Finish building **simulator**, completing **receding horizon comparisons**.
- Integrate new generation expansion planning tool (**E4ST v2**) into MATPOWER suite.
- Explore a Newton-based coordination scheme to resolving **AC MOPS convergence issues.**
- Support other projects using MATPOWER/SuperOPF tools and frameworks.

Questions?