USBR PLEXOS® Demo

November 8, 2012
Who We Are

- PLEXOS Solutions is founded in 2005
- Acquired by Energy Exemplar in 2011

Goal
- To solve the challenge problems facing the energy industry by providing simulation and optimization software and consulting services

People
- All principals have over 20 years simulation software development and consulting experience
- All principals have Master degrees or Ph.D. in the engineering, economics and mathematics fields

Three business areas
- Support to the Power Market Simulation Software PLEXOS
- Information Service: Daily WECC Term forecast
- Consulting
PLEXOS Applications

PLEXOS is used by ISOs, utilities, generators, consulting firms and governmental agencies for:

- **Operations**
  - Day-ahead generation scheduling (unit commitment and economic dispatch) to minimize cost or maximize profit
  - Variable energy resource integration analyses

- **Planning and Risk**
  - Integrated resource planning
  - Utility planning and energy budgeting
  - Portfolio risk evaluation

- **Market Analysis**
  - LMP and AS market price forecast

- **Transmission (Network) Analysis**
  - Economic transmission expansion
  - CRR (or) FTR valuation
About PLEXOS

PLEXOS is a MIP-based next-generation energy market simulation and optimization software

- Co-optimization architecture is based on the Ph.D. work of Glenn Drayton*
- Advanced Mixed Integer Programming (MIP) is the core algorithm of the simulation and optimization
- Foundation for the mathematical formulation of the New Zealand, Australia, Singapore and ISO day-ahead markets in the US and Canada
- PLEXOS licensed in United States, Europe, Asia-Pacific, Russia, and Africa (17 countries, about 100 sites)

PLEXOS Algorithms

- Co-optimize thermal, hydro, energy / reserve / fuel / emission markets and contracts
- No iterations, no heuristics.
- User defines business constraints
- Intra-hour interval optimization
- Results can be independently audited *i.e.* simulation engine is not a black-box
- Naturally provides physical (primal) as well as financial (dual) output *e.g.* provides information on shadow prices which can be of crucial for your operating and planning decisions
Solving UC/ED using MIP

Unit Commitment and Economical Dispatch can be formulated as a linear problem (after linearization) with integer variables of generator on-line status.

Minimize Cost = generator fuel and VOM cost + generator start cost
+ contract purchase cost - contract sale saving
+ transmission wheeling
+ energy / AS / fuel / capacity market purchase cost
- energy / AS / fuel / capacity market sale revenue

Subject to
- Energy balance constraints
- Operation reserve constraints
- Generator and contract chronological constraints: ramp, min up/down, min capacity, etc.
- Generator and contract energy limits: hourly / daily / weekly / ...
- Transmission limits
- Fuel limits: pipeline, daily / weekly/ ...
- Emission limits: daily / weekly / ...
- Others
Integration of Mid- and Short-Term Constraints

- PLEXOS includes three integrated algorithms:
  - Long-term security assessment
  - Mid-term simulation
  - Short-term simulation

- Security, mid-term and short-term considerations are seamlessly integrated

- Mid-term simulation decomposes medium-term fuel, emission, and energy constraints for the short-term simulation
Detailed Generator Modeling

- General chronological constraints modeled, i.e.,
  - Minimum up and down time
  - Ramp up and down rate
  - Minimum capacity with hourly economic or must-run status
  - Reserve (regulation up/down, spinning and non-spinning) provision capacities
  - Start cost as a function of number of hours being down
  - Forbidden operation zone
- User-specified fuel mixture / mixture ranges or model-determined fuel mixture
- Heat Rate as a function of fuel types
  - Average heat rate for multiple loading points
  - Incremental heat rate for multiple loading points
  - Polynomial fuel-generation IO curve
- Emission rate with removal rate
- Initial commitment and dispatch status
Combined Cycle Modeling

- Component modeled individually
  - Combustion Turbine (CT)
  - Heat Recovery Steam Turbine (HRSG)
  - Steam Turbine (ST)
  - Duct Firing
  - Thermal load (cogeneration)

- Components tied together through linear or piecewise linear constraints

- Components optimized simultaneously with MIP algorithm
Combined Cycle Modeling, continued

- Fuel = 1.68e+9 Btu
  - HR = 10500 Btu/kWh
  - Efficiency = 32.5%
  - Gen = 160 MWh
  - Waste = 1.134e+9 Btu

- Duct Burner
  - Fuel = 1.45e+8 Btu
  - HR = 10500 Btu/kWh
  - Efficiency = 32.5%

- Boiler efficiency = 80%
  - HR = 10316 Btu/kWh
  - Efficiency = 33%
  - Gen = 190 MWh

Energy content of electricity = 3412 Btu/kWh
Detailed Fuel Modeling

- Hourly fuel dispatch prices versus fuel accounting prices
- Tax by fuel
- Transport charge by generator
- Hourly / daily / weekly / monthly / annual fuel lower and upper limits
- Take-or-pay fuel contracts with take-or-pay price
- User-defined pipeline limits (using user-defined Constraints) and hourly burner tip limits
- Trade with fuel markets
Detailed Emission Modeling

- Emission rate by fuel or by generation or both
  - Emission rate by generation for multiple loading points
- Emission dispatch price versus emission accounting price
  - Dispatch price is automatically included in generator dispatch cost
  - Accounting price is used for production costing
- Hourly / daily / weekly / monthly / annual emission cap (using user-defined Constraints)
- Emission cap by (sub-)region or by (sub-)fleet
- Trade with emission markets or hard cap or both
Detailed Energy Contract and Transmission Modeling

- Off-system purchase or sales
  - Hourly volumes and prices
  - Fixed cost and fixed energy charge
- Bilateral contracts with both delivering and receiving parties modeled
- Call or put options with strike prices
- Transport or DC-OPF modeled
  - Line limits
  - Interface limits
  - Losses
  - Wheeling charges
Cascaded Hydro Systems

- **Reservoir**
  - Natural Inflow (AF/h)
  - Initial/Max/Min storage (AF)
  - Connecting waterway, generators
  - Storage target (AF)
  - Water value ($/AF)

- **WaterWays**
  - From a reservoir to another reservoir or “to the sea”
  - “Max flow” and “Min flow” in AF/h
  - Flow ramp rate “Max Flow Delta” in AF/h/h
  - Flow delay: “Traversal Time” in hour

- **Hydro and P/S generators**
  - Water efficiency as a function of generation load points
  - Different cycle efficiencies or ratings for different units
An Example of Cascaded Hydro System
Market

- Energy markets: Exogenous power markets are connected to one or more transmission nodes. Trades to and from the energy market are made at these buses.
- Fuel: Arbitrage between a fuel contract and a spot fuel market.
- Reserve Markets: Reserve requirement can be taking/provided by external markets.
- Capacity: Generators receive revenue from the capacity as a function of their availability
Stochastic Capabilities

Any simulation variable can be treated stochastically provided data are available

- Endogenous sampling
  - Model-generated samples for given distribution

- Exogenous sampling
  - User-specified samples

- Stochastic sample correlation
Net System Production Cost Distribution

Production Cost Histogram

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<th>Frequency</th>
<th>Probability</th>
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million $
LT-Plan: PLEXOS for Integrated Resource Planning

Objective: Minimize net present value of forward-looking costs (i.e. capital and production costs)

\[
\text{Objective: Minimize } \text{Total Cost } C(x) + P(x)
\]

- **Production Cost** \( P(x) \)
- **Capital Cost** \( C(x) \)
- **Total Cost** \( C(x) + P(x) \)

Optimal Investment \( x^* \)
New Addition/Retirement Candidates

- Hydro
- Wind
- Geothermal
- Fossil
- Transactions
- Demand side participation
- Transmission augmentations
LT Plan: Constraints

- **Investment Constraints**
  - 10 - 30 year horizon
  - Minimum zonal reserve margins (% or MW)
  - Maximum reserve margins (optional)
  - Inter-zonal transmission expansion (bulk network)
  - Resource addition and retirement candidates (i.e. maximum units built / retired)
  - Build / retirement costs
  - Age and lifetime of units
  - Technology / fuel mix rules

- **Operational Constraints**
  - Energy balance for each TOD and each month
  - Ancillary Service requirements
  - Power flow limits
  - Resource limits: energy limits, fuel limits, emission limits, etc.
  - Others
A Portfolio Example

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