Operation Simulation Associates, Inc.

PowrSym4

A Presentation by

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Presentation Contents

- History of PowrSym
- Introduction to OSA
- The PowrSym3 Model
- PowrSym4 Enhancements

PowrSym Background

- PowrSym1 developed for TVA in 1970's
  - Placed in public domain
  - Foundation for PowrSym Plus (also called P+)
- PowrSym2 developed by OSA in 1980's
  - Foundation for PROSYM
- PowrSym3 developed by OSA mid 1990's
  - Enhancement has been on-going
  - Addition of NTC multi-area flow logic
  - Unique features for modeling wind power, cogeneration and energy storage
- PowrSym4 Nodal released in 2010
  - PTDF multi-area flow logic (Zonal or Nodal by Bus)
  - Interface to transmission models
  - Enhancements for multi-area adequacy studies using Monte Carlo uncertainty algorithm.

PowrSym General Overview

- Chronological Simulation
- Energy Storage
- Unit Commitment (Dynamic, Multi-state)
- Monte Carlo Uncertainty, Probabilistic
- Combined Heat & Power
- Blast Furnace & Steel Converter Gasses
- Multi-Area (LTC or PTDF)
- Zonal LMP (Locational Marginal Pricing)

PowrSym Overview Continued

- Wind & Solar Energy
- Maintenance Scheduling
- Fuel Contracts
- Load Flow Interface by TenneT & T.U. Delft
- Zonal & Nodal LMP with PTDF Flow Scheduling
- Computation time in range of seconds for detailed week simulation to a couple of hours for an annual simulation of a multi-region grid.

PowrSym3 - Features

- Input & Output are Keyword driven records
  - Easy to manipulate by database or Excel
- Multiple Areas Simulation
- Chronological, by hours or minutes (time step user definable)
- Combination of heuristic & dynamic commit
- Equal incremental cost dispatch
- Combined heat and power <u>optimization</u> (not as constrained units)
- Hydro, Pumped Hydro, Wind Power
- Fuel Contracts and Limitations

Marginal Costs

- Hourly or minutes
- Market Depth Curve
- Incremental/Decremental
- As viewed by each area

Cost Model

- PowrSym3 is a least cost generation model
- Marginal costs are:
  - Last unit dispatched
  - Purchase power
  - Unserved energy cost
  - Dump power cost
  - Vary by area
    - Wheeling costs
    - Transmission constraints

Maintenance

Maintenance Scheduler Module:

- Internal model with as objective functions:
  - Levelized LOLP
  - Least Cost
- Allows combination of objective functions
- Allows External schedule
- Will schedule in mixed mode

Maintenance Evaluator (PME)

- Designed to evaluate maintenance options under uncertainty
- A Monte Carlo risk model works through a wide range of uncertainties producing a probabilistic evaluation of maintenance schedules and options
- Not just a single “expected” result but also a graphical depiction of the range of possible outcomes

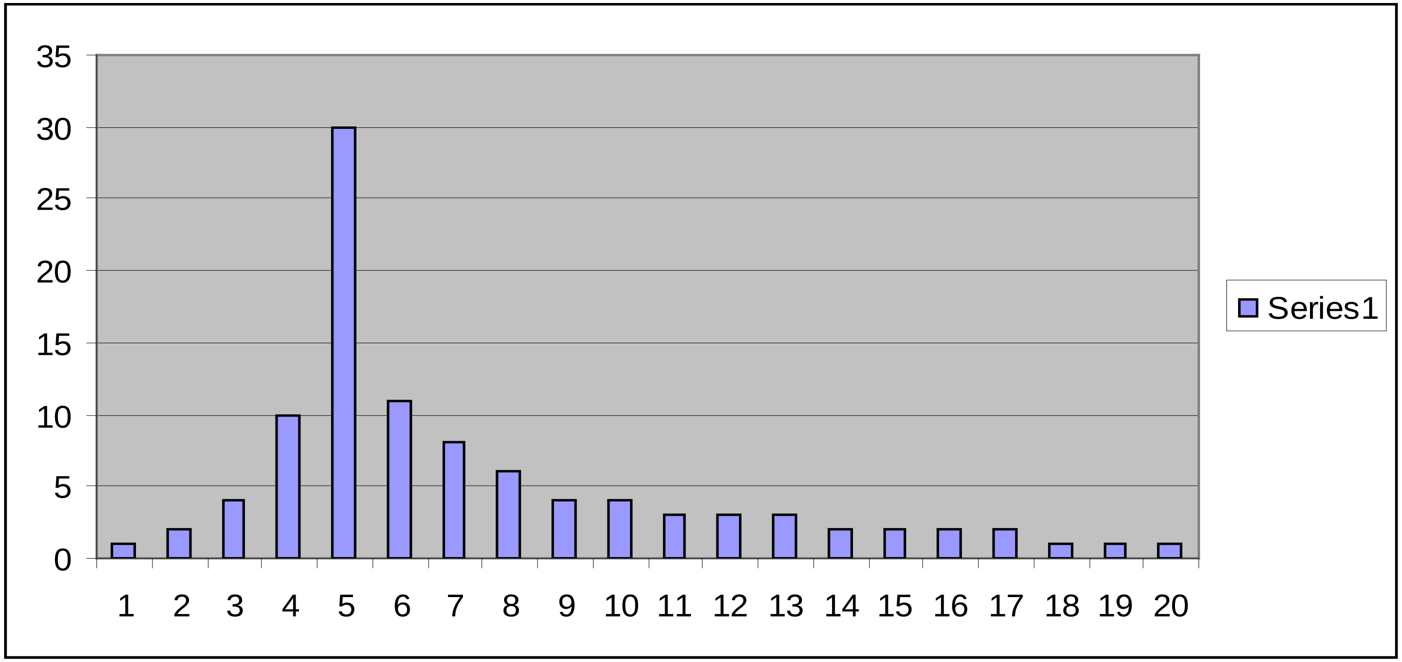
Probabilistic Model

- Monte Carlo iterative model
  - Unit outages and deratings
  - Network outages or deratings
  - Wind & Solar variance
  - Hydro variance
  - Load variance
- Average results
- Range of results across the draws

Sample Monte Carlo Analysis

- The following graph shows resulting production costs for a one week extension of an outage. The y axis is percent chance of falling in that bracket and the x axis is system production cost increase in $100,000 increments.

Monte Carlo Analysis



Monte Carlo Analysis

- A simple computation would likely yield the $500,000 result, but the risk analysis yields an expected cost of $742,000 and some probability that costs could exceed $2 million.
- Similar graphs can be produced for changes in other outputs such as marginal costs, fuel consumption and emissions.

Reliability model

- Standard LOLP calculation
  - Does not include wind/solar variation
  - Does not include all unit operating constraints
  - Does not include network constraints
- LOLE calculation
  - Probability and depth
  - Includes load, wind and solar variation
  - Includes unit operating constraints
  - Includes network constraints
  - Results from Monte Carlo draws

Reserves Model

- Spinning, operating, standby, turndown
- System, Control Area, Area
- Units
  - Standard, quickstart, nonfirm
  - Min and Max contribution
  - Ramping limits

Unit Commitment

- Heuristic, DP, or combination
- Minimum up/down times
- Start costs
- Multi-state stations
- Pumped and Conventional Hydro

Unit Dispatch

- Economic Observing Constraints
- Combined Heat and Power Units
- Multi-Area including transmission constraints
- Equal incremental cost

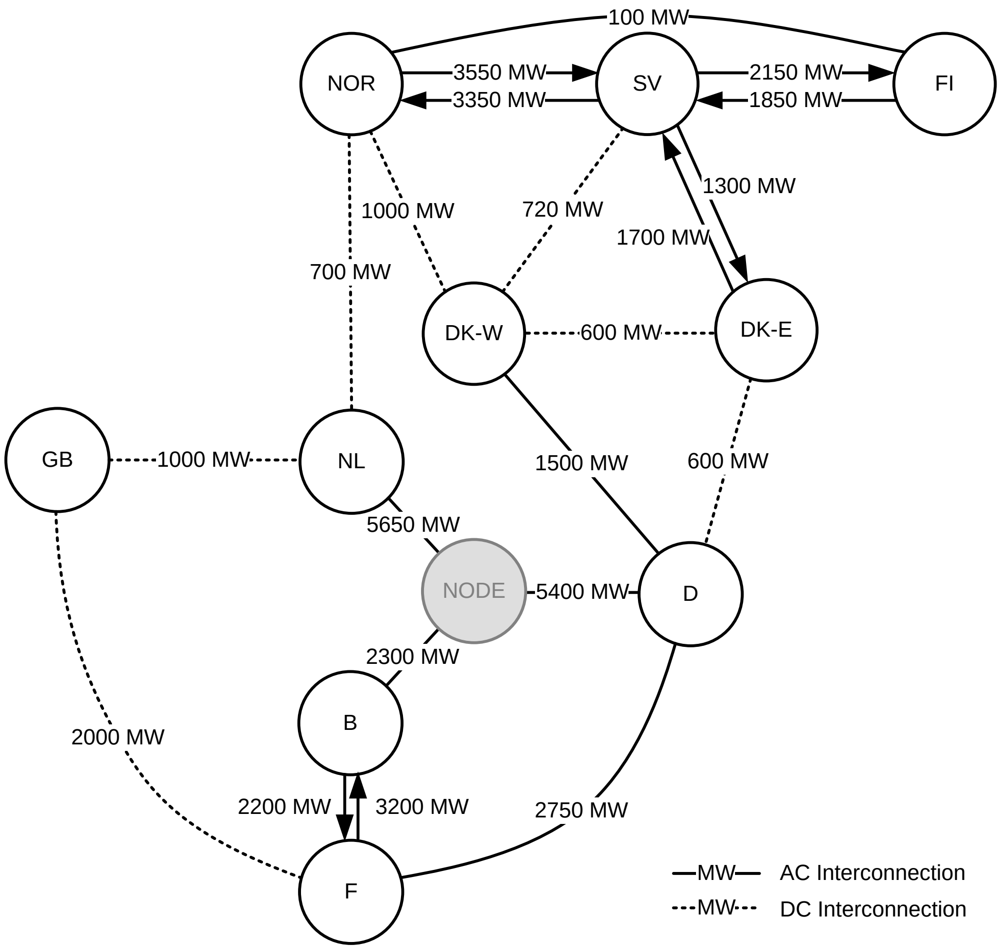
Multi Area

- The system may be divided into areas
- Areas may be grouped into control areas
- Adapted, robust spinning and operating reserve model (including turn-down reserves)

Multi Area

- Areas are connected by links with capacity, loses, and transmission charges parameters
- Link parameters may vary by direction of flow and by time of day.
- Transfer Capabilities (NTC & PTDF)

Multi Area



Source: TenneT

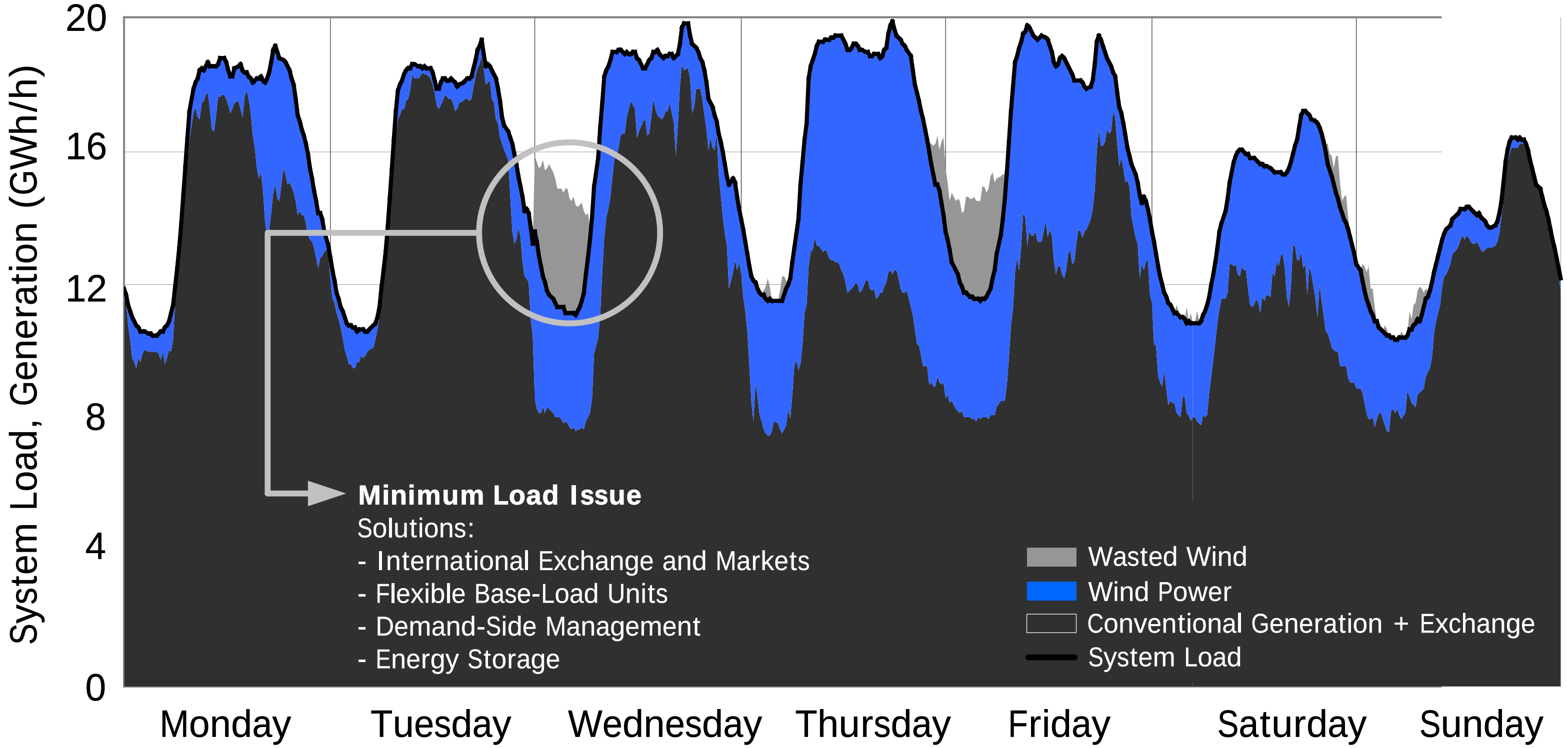
Wind Power

- Wind is treated as a resource
  - Hourly Generation derived from Wind Patterns (not “Negative Load” approach)
- No practical Limit on Number of Wind Farms
- Multiple wind regimes linked to multiple wind farms.
- Each wind farm has its own conversion equations.

Wind Power

- Uncertainty on Wind Power Generation (Monte Carlo)
- Different options for the curtailment (inflexible to flexible)
- Option to use wind power prediction models and wind prediction accuracy functions in the unit commitment
  - Prediction on hourly basis (rolling horizon)

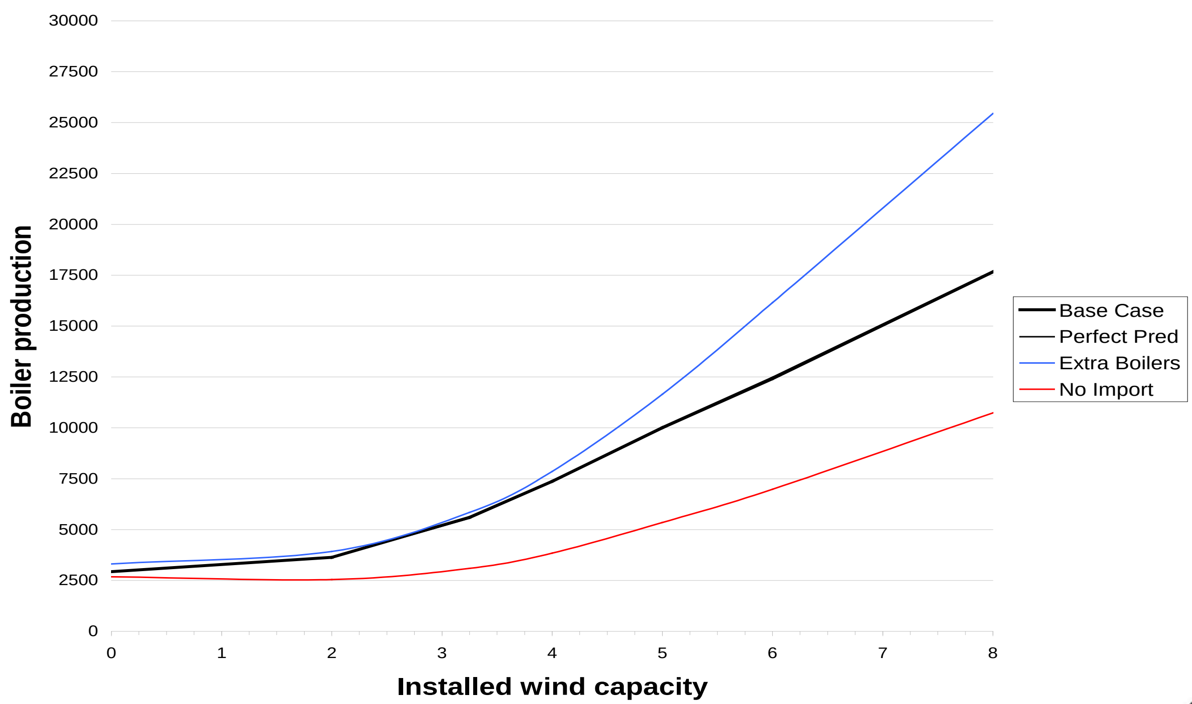
Wind Power
Case Study – The Netherlands



Source: TenneT TU Delft Technische Universiteit Delft

Wind Power
Case Study – The Netherlands

Impact of Wind Generation on HOB's production



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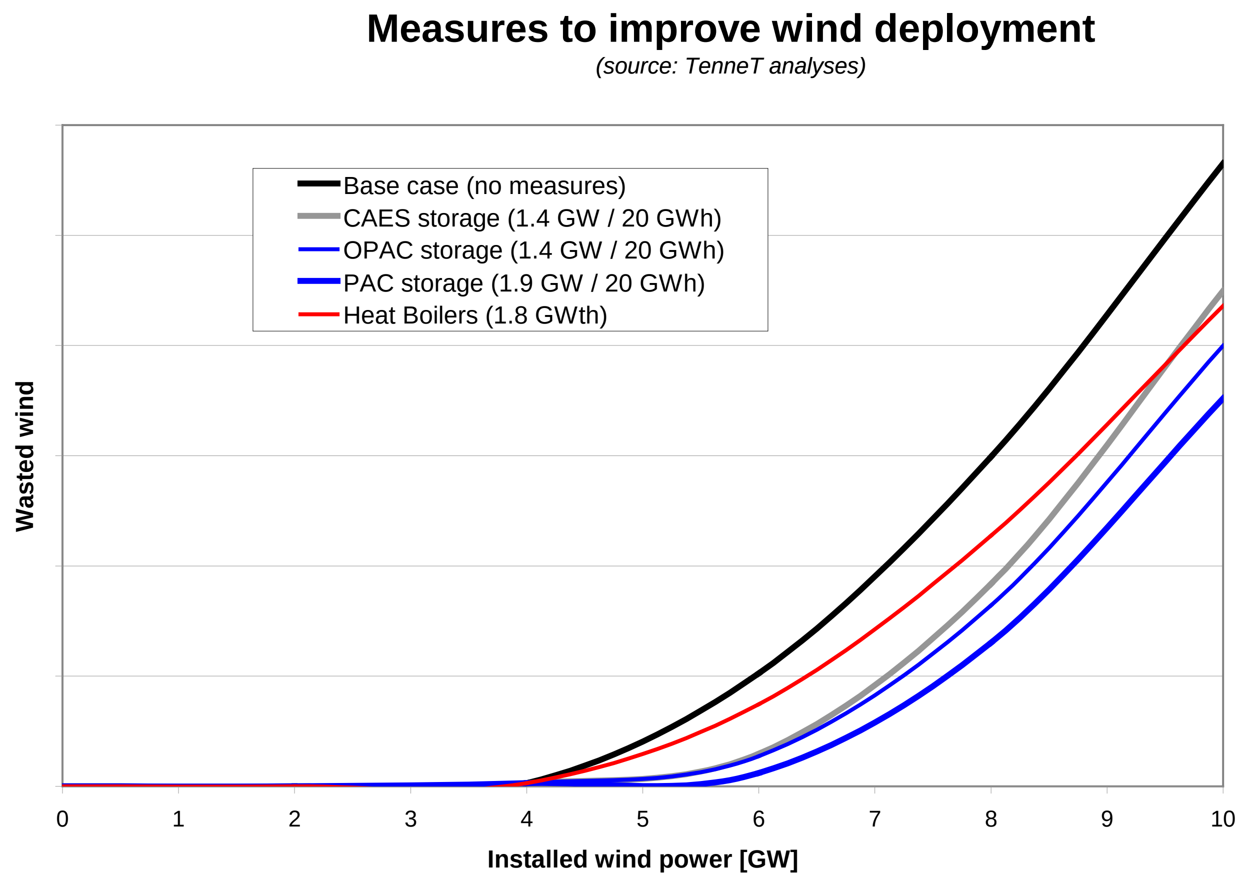
Wind Power
Case Study – The Netherlands



Source: TenneT

Cogeneration (CHP)

- Unique methodology and simulation technique
  - Gives a direct lowest cost solution (not iterative) for serving the combination of electric and heat loads
  - Heat areas with unique hourly heat loads, served by unique combinations of CHP units, heat-only boilers or heat storage units
  - Heat networks with capacity limits and losses
  - Two concomitant heat extractions possible (low and high temperature)

Emissions Dispatch

- Multiple Effluents
- SO_2 / NO_X / CO_2 / OTHERS
- PowrSym3 reports the emission levels
- Operations may be influenced by prices attached to various effluents (option)

Fuel Contracts and Limitations

- Fuels may be input as a station parameter or fuels may be input as their own entity
- In the second case:
  - Fuels may be shared by multiple stations
  - A station may have access to multiple fuels
  - Station capacities and efficiencies may vary by fuel selection
  - Fuels may be blended
  - Fuels may have varying transportation costs to the various stations

Fuel Contracts and Limitations

- Energy Limited Fuel Dispatch (ELF)
  - Multiple fuel contracts with different prices, reliability and limits
  - Quantity and prices may vary by hour
  - Inventories, storage rate limits
- Each fuel delivery, inventory, or transportation constraint can be probabilistically derated
- Integrated with Monte-Carlo simulation

Fuel Contracts and Limitations

- Use of residual Blast Furnace Gas (BFG) and Oxygen Converter Gas (OCG)
  - Low calorific value
  - Fluctuating quantities
  - Support firing of natural gas (NG) needed
  - Automatic correction of unit efficiency and capacity, function of the amount of BFG burned
  - Different prices for BFG, OCG and NG

Energy Storage

- Time related constraints are a major factor in the pump hydro dispatch:
  - Turn-down limits on large thermal power plants may create low cost pumping opportunities even in high load periods
  - Cogeneration and power exchange contracts may have time-of-day provisions not following always system load swings
  - Availability of variable sources such as wind and solar.

Energy Storage

- Such constraints often cause pumped hydro operation to deviate from the intuitive schedule of pumping during lowest load hours and generating during highest load hours
- Solved by VALUE OF HOURLY ENERGY, not just load leveling (valley filling peak shaving technique)

Energy Storage

- Value of Energy Method:
  - Places a cents/kWh value on the energy in storage, defined relative to pumping mode
  - When marginal cost of other resources < the pumping energy value, the plant would be operated in pumping mode (subject to storage availability)

Energy Storage

- Value of Energy Method (contd.):
  - Generating value is the pumping value divided by plant net efficiency + plant variable O&M cost
  - When system marginal cost > generating value of energy, the plant is operated in generating mode

Energy Storage

- Value of Energy Method (contd.):
  - A reservoir empty condition is not allowed during a period of high marginal cost. This requirement places a lower bound on the pumped hydro energy value
  - An additional lower bound is defined by the requirement that sufficient pumping energy must be available to replace generation energy plus efficiency losses over the study horizon

Energy Storage

- Value of Energy Method (contd.):
  - The value of energy which results in optimal pumped hydro scheduling can now be defined as the higher of these two lower bounds.
  - The first bound will control for projects with small reservoirs and the second bound for larger reservoirs

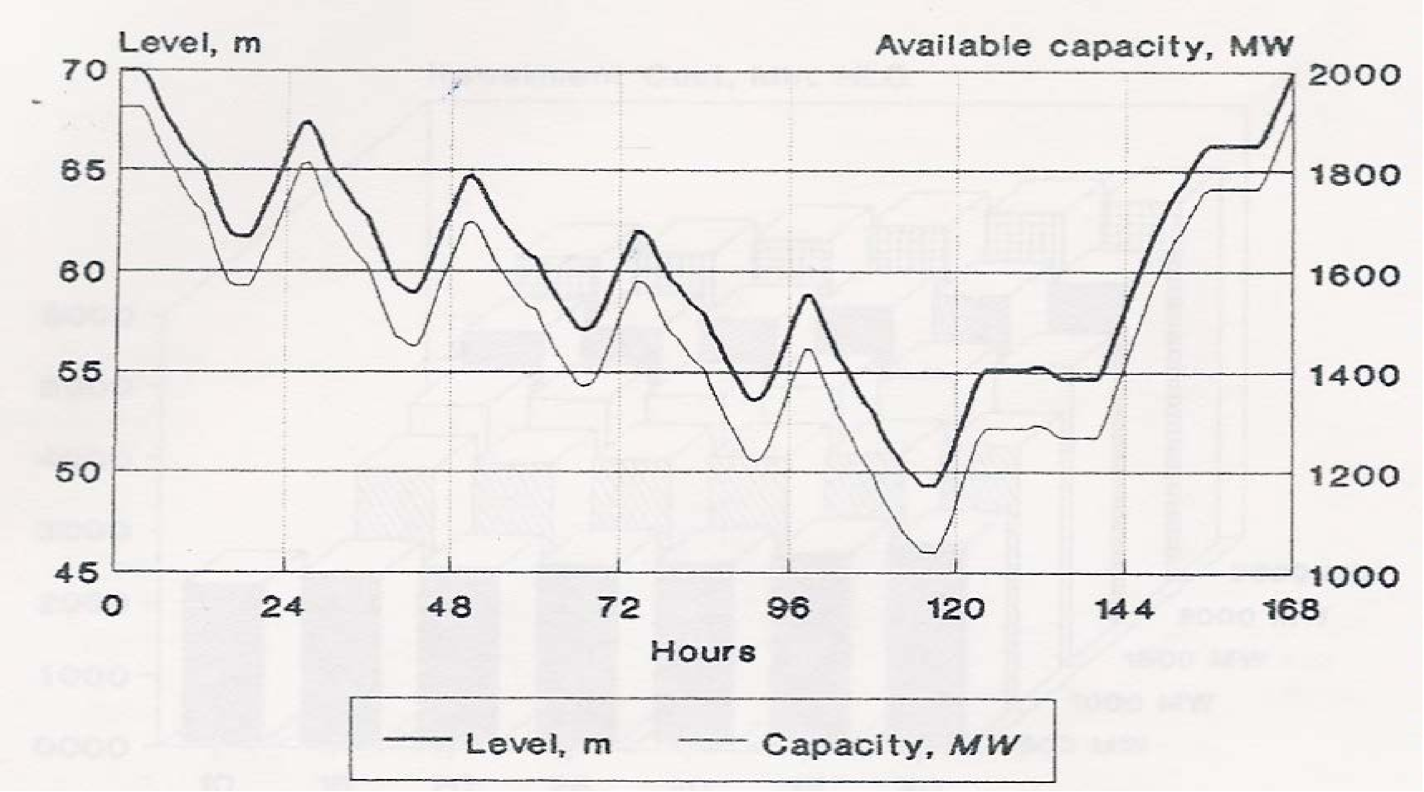
Energy Storage and Adequacy

- For speeding-up the calculations for large Monte Carlo adequacy studies, a simplified, quick pumped hydro scheduler has been developed.

Energy Storage

Low head pumped storage systems

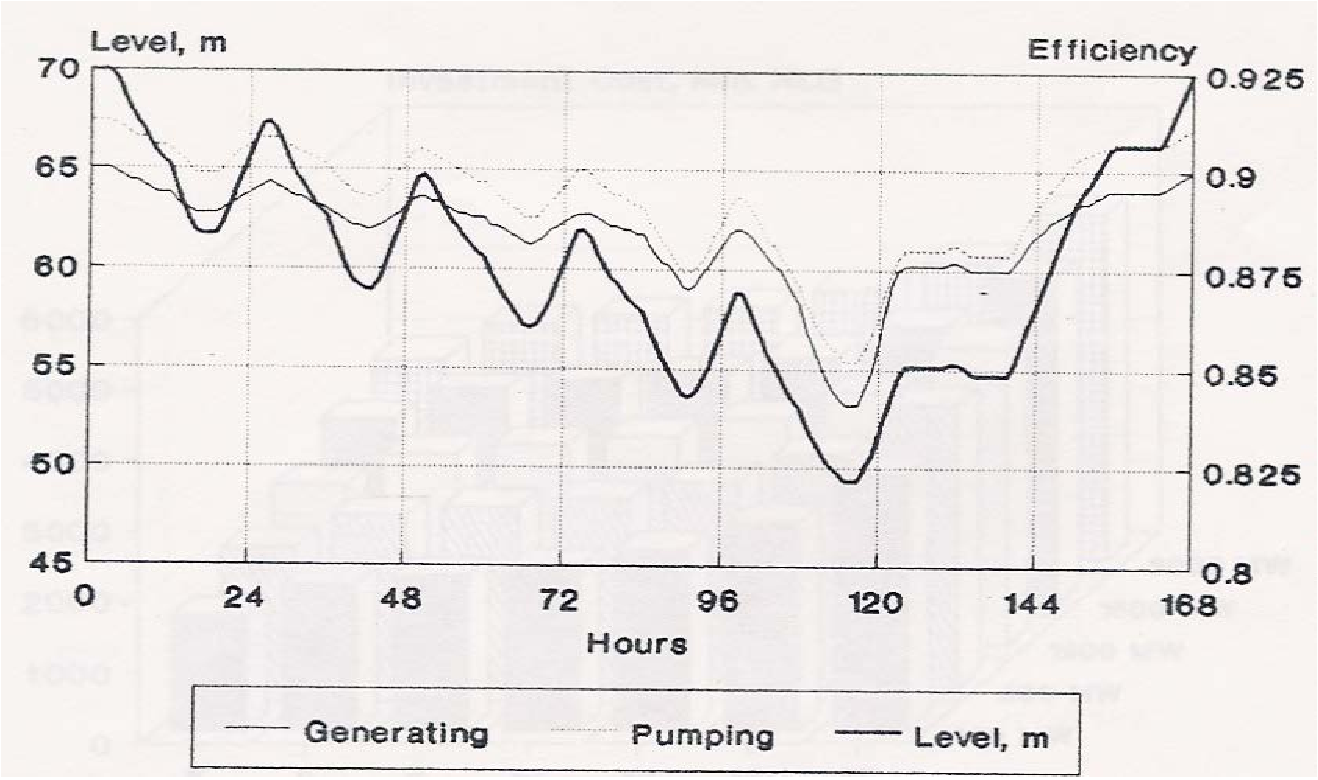
high variation of the available capacity



Energy Storage

Low head pumped storage systems

high variation of efficiency



Hydro Logic

- Hydro may be modeled by a load-leveling method, including the variation in wind/solar generation.
- Alternatively hydro (or a portion of the hydro) can be modeled by the value of energy method
- Forward of information (reservoir levels, spillage) from week to week

DP Algorithm

- Models for multi-mode combined cycle units (also CHP) in different states (GT, GT+ST, ST) and, of course, single-state units
- Three states plus off-line, may be extended to additional states
- Modeling of state transitions, up and down (transition times, transition cost)
- Uses DP logic to optimize state selection
- Important option because of increasing number of Combined Cycle units

Advantages of PowrSym3

- Combination of LP, heuristics and DP makes the model very accurate, while maintaining a very high computational speed
- This delivers operation quality answers, the model being also in operation in dispatch centers

Advantages of PowrSym3

- The accuracy, in combination with the high speed allow for adequate security analysis of very large systems, while considering chronological and correlation aspects within market simulation.

PowrSym4 Enhancements

- Combining market simulation with load flow calculations:
  - Increased uncertainty of load flows due to increased liberalization and large-scale integration of RES (wind)
  - Necessity to combine Unit Commitment & Economic Dispatch (UC-ED) with load flow simulations

PowrSym4 Enhancements

- Results from UC-ED, defined with PowrSym4, form input for load flow models (like PSS™E or others)
- PowrSym4 accepts NTC or PTDF factors from the load flow models

PowrSym4 Enhancements

- Results from all daily load flows of a year give a good approximation of all possible combinations between load and generation throughout that year
- Technique applicable for use in combination with any load flow model

Power Transmission Distribution Factors (PTDFs)

- The PTDF is the fraction of the amount of a transaction from one node (or zone) to a defined central node that flows over a given transmission line.
- Dynamic PTDF factors are relative to a given flow balance.

PTDF Factors

- The PTDF array can be very large, in theory a value for every branch relative to each node.
- In practice many of the array values are near zero and only the significant values are required for input.

PTDF Flow Calculations

- Flows between specific nodes are computed by:
  - Scheduling a flow from the sending node to the central node.
  - Scheduling a negative flow from the central node to the receiving node.

PTDF Flow Optimization

- The PTDF flow logic is integral to the PowrSym commit and dispatch logic.
- Flows are scheduling so as to find the least cost result with minimal un-served energy.

Locational Marginal Price (LMP) Forecasting Using PTDF

- PowrSym4 produces hourly LMP output for each zone in zonal studies and each node in nodal studies.
- The LMP output can be expressed as a range in Monte Carlo analyses.

Current Development Projects

- Improved method for use of multiple processors in large Monte Carlo studies.
- A faster PTDF algorithm.
- Additional features related to natural gas storage reservoirs.
- FBA-MC (Flow Based Allocation – Market Coupling): zonal PTDFs will be used for linking commercial transactions to the physical structure of the grid.

Current Development Projects

- Allocation of social benefits per region or stakeholder group:
  - Social welfare (benefits – costs)
  - PowrSym calculates the benefits for the entire system (market surplus = reduction of production costs)
  - Assuming that electricity is sold at marginal cost in each node → allocation per region or stakeholder group