Stochastic Modeling and Supercomputing for Smart Grids

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Eugene A. Feinberg
Department of Applied Mathematics & Statistics
Stony Brook University

James Glimm (SBU), Janos Hajagos (LIPA), Jiaqiao Hu (SBU), Eting Yuan (SBU)
Smart Grids and Supercomputing

- Smart grids will generate large amounts of sensor measurements whose timely processing and utilization will be used to improve efficiency and reliability.
- Intermittent energy sources (wind, solar) increase supply uncertainties.
- Parallel computing provides natural tools for data processing, optimal decision making and uncertainty modeling.
Advantages of HPC

- High performance compilers
- Parallelism: doing many things at the same time
  - Instruction-level parallelism: doing multiple operations at the same time within a single processor (e.g., add, multiply, load and store simultaneously)
  - Multiprocessing: multiple CPUs working on different parts of a problem at the same time
    - Shared Memory Multithreading
    - Distributed Multiprocessing
- Powerful storage hierarchy
What is High Performance Computing?

- **High Performance Computing (HPC)**, also called supercomputing, is the biggest, fastest computing right this minute. Likewise, a **supercomputer** is one of the biggest, fastest computers right this minute. So the definition of supercomputing is constantly changing.

- New York Blue:
  - Consists 18 racks IBM Blue Gene
  - Each rack consists of 1024 compute nodes (a total of 18432 nodes)
  - Each node consists two 700 MHz PowerPC 440 core processors and 1 GB of memory (a total of 36864 processors and 18.4 TB of memory)
  - Top 500 Supercomputer ranking: 67 as of 06/2010 (17 as of 06/2008)
Some Applications of HPC

- **State Estimation**
  - Estimate the steady states condition of EPS using online measured values
  - The measurement system consists of active and reactive line power flow and bus injection real and reactive power measurement and bus voltage magnitude measurement

- **Forecasting**
  - Weather forecasting
  - Load, price, capacity, equipment states, rating and reliability, etc.

- **Control and Planning**
  - Unit Commitment Problem, Economic Dispatch
  - Power Flow Control
State Estimation

- Provide reliable estimates of the quantities required for monitoring and control of the EPS
- A set of measurements obtained is centrally processed by a static state estimator
  - Higher frequency -- shorten the time interval between consecutive state estimations to allow a closer monitoring of the system evolution particularly in emergency situations in which the system state changes rapidly
  - Larger size -- enlarge the supervised network by extending state estimation to low voltage sub networks
State Estimation

Challenges:

- Higher frequency requires the development of faster state estimation algorithms
- Larger size increase the demand on the numerical stability of the algorithms

Solutions:

- Parallel and distributed implementations of the state estimation function
State Estimation

State Estimation model:

\[ z = h(x) + w \]

- \( z \) – \((mx1)\) measurement vector
- \( x \) – \((2nx1)\) true state vector
- \( h(.) \) – \((mx1)\) vector of nonlinear functions
- \( w \) – \((mx1)\) measurement error vector
- \( m \) – number of measurements
- \( n \) – number of buses
Load Forecasting

- Accurate forecast of future demand required by all entities involved in the energy markets
  - Electric Utilities
  - Independent System Operators
  - Power Marketers
- Different forecast horizons
  - Long Term: Several years out – required for planning purposes
  - Mid Term: Several weeks to months – scheduling maintenance, planning fuel supply, transactions
  - Short Term: Next hour to next week – daily operation, energy transactions, reliability studies
Regression Models: Example

- \( L(t) = F(d(t), h(t)) \cdot f(w(t)) + R(t) \)
  - \( L(t) \) – Actual load at time \( t \)
  - \( d(t) \) – day of the week
  - \( H(t) \) – hour of the day
  - \( F(d,h) \) – daily and hourly component
  - \( w(t) \) – weather data that include the temperature and humidity
  - \( f(w) \) – weather factor
  - \( R(t) \) – random error
Forecasting using ANNs: Example

Predict = \sum \text{Sigmoid Node Output} + \text{Error}
Unit Commitment Problem

- Optimal generator assignment problem for electric grid
- Schedule the power generator units over a short time period, in order to:
  - Minimize the operation cost
  - Satisfy the electricity demand
  - Maintain system reliability
- Formulation: Mixed Integer Programming Problem
Unit Commitment Problem

- **Challenges**
  - Large scale mixed integer programming: thousands of integer and continuous variables, numerous security constraints
  - Uncertainty in electricity loads
  - Volatile energy sources: wind energy, solar energy

- **Solutions**
  - Parallel implementation of UCP solver to boost computational speed
  - Stochastic modeling of uncertainty
Effectiveness of Parallel Computing

Computational time (in seconds) vs. Number of CPU’s

Number of power generators: 1000