Cyber Infrastructure for the Smart Grid

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Smart Grid Measurements and Timeline for Compute, Control
Sense: Smart Meters

- For power consumption and demand response
- Parameters to be measured
  - kW, peak kW, power factor etc.
- Frequency of measurement
  - 15 minutes, 1 hour, daily, monthly
- Frequency of uploading, communicate
- Other
  - Control
  - Home monitoring
  - Demand side management
Sense: Smart Meters

- Electromechanical meters
  - Low accuracy, expensive add-on communication, no control

- Solid state digital Meters
  - High accuracy, add-on communication, limited control

- Next generation integrated meters
  - High, integrated communication, enhanced control
Communicate

- Microwave,
- Satellite,
- Radio or Wireless,
- Fiber Optic,
- Power line communication
Power system states

- **Normal**: Load met, good voltage, No overloads, Minimum costs
- **Alert**: Load met, Voltage problems, Short term overloads, Minimum costs
- **Emergency**: Load largely met, Severe voltage, Overloads, Costs not major concern
- **Blackout**: Load lost, Cost not concern, Corrective action limited

**Restoration**
Load Shed, Cost not concern, Corrective action Priorities
Visualize
Visualize
Visualize
Control

Corrective action:

- Causes the transitions from alert to normal state with tactical control

Remedial Action Scheme

Preventive action

- Strategic control minimize or eliminate transitions from alert to emergency state or to blackout state

Security Analysis, OPF

Systematic restoration process are needed in order to recover from a blackout

Automatic control
Compute and Control: Energy Management System
Compute and Control: Applications and Timeline

- **1-10 yr**
  - System Planning
  - Forecasting/Production Cost Analysis
  - Maintenance

- **Month**
  - Unit Commitment
  - Security Analysis
  - Interchange Contracts

- **Day**
  - Unit Commitment
  - Security Analysis
  - Voltage/Power Flow manual Control

- **30 min**
  - Transactions
  - Security Analysis

- **5-15 min**
  - Economic Dispatch
  - State Estimation

- **~4 s**
  - SCADA/ Automatic Generation Control

- **ms**
  - Relaying/ Voltage and Excitation control
Compute and Control: Applications and Timeline

Sauer and Pai “Power System Dynamics”

- Lightning Propogation
- Switching Surges
- Stator Transients and Subsynchronous Resonance
- Transient Stability
- Governor and Load Frequency Control
- Boiler and Long Term Dynamics

Timeline:
- $10^{-7}$
- $10^{-5}$
- $10^{-3}$
- 0.1
- $10^1$
- $10^3$
- $10^5$

Operations:
- min
- hour
- day
- month
- year
- decade

Planning:
- Douglas
- Match
- Forecast
## Compute and Control: Multi-scale Dynamics in Power System

<table>
<thead>
<tr>
<th>Action/operation</th>
<th>Time frame</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wave effects (fast dynamics, lightning caused over voltages)</td>
<td>Microseconds to milliseconds</td>
</tr>
<tr>
<td>Switching over voltages</td>
<td>Milliseconds</td>
</tr>
<tr>
<td>Fault protection</td>
<td>100 milliseconds or a few cycles</td>
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<tr>
<td>Electromagnetic effects in machine windings</td>
<td>Milliseconds to seconds</td>
</tr>
<tr>
<td>Stability</td>
<td>60 cycles or 1 second</td>
</tr>
<tr>
<td>Stability Augmentation</td>
<td>Seconds</td>
</tr>
<tr>
<td>Electromechanical effects of oscillations in motors &amp; generators</td>
<td>Milliseconds to minutes</td>
</tr>
<tr>
<td>Tie line load frequency control</td>
<td>1 to 10 seconds; ongoing</td>
</tr>
<tr>
<td>Economic load dispatch</td>
<td>10 seconds to 1 hour; ongoing</td>
</tr>
<tr>
<td>Thermodynamic changes from boiler control action (slow dynamics)</td>
<td>Seconds to hours</td>
</tr>
<tr>
<td>System security monitoring</td>
<td>Steady state; on-going</td>
</tr>
<tr>
<td>Load Management, load forecasting, generation scheduling</td>
<td>1 hour to 1 day or longer, ongoing</td>
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<tr>
<td>Maintenance scheduling</td>
<td>Months to 1 year; ongoing</td>
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<tr>
<td>Expansion planning</td>
<td>Years; ongoing</td>
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<tr>
<td>Power plant site selection, design, construction, environmental impact, etc.</td>
<td>10 years or longer</td>
</tr>
</tbody>
</table>
Compute and Control: *Tools*

- **Planning Tools (years):** Simulate long-term scenarios (NEPLAN, PROMOD, PSS/E, PSLF, etc.)
- **Operational Support Tools (days):** Simulate operational scenarios (Markets, Gen scheduling, PSS/E, etc.)
- **Operation Tools:** Handle real time operation in control center. (SCADA, AGC, EMS Applications, etc.)
- **Simulation tools:** Overlap between above functional tools
  - Steady state analysis tools
  - Electromechanical dynamic analysis tools
  - Electromagnetic dynamic analysis tools
  - Optimization