Electric Power Systems Engineering: Review and Open Questions

• Introduction
• Operation Objective
• Classification of Operation Modes
• EPSE Under Normal Conditions
• EPSE Under Emergency Conditions
• Challenge in Changing Industry Infrastructure
• Open Questions
What is EPSE: Definition

• Systems perspective of modeling, analysis, decision-making for operating and planning of electric power grids.
• Evolve as the electric power industry evolves.
What is EPSE: Objective

• Operating the power system in a reliable and efficient way
Brief Review of Power System

• Physical structure and components
  – Generation
  – Transmission
  – Distribution
  – Consumption

• Organizational structure
  – Before: regulated, vertical monopoly
  – Now: approaching deregulated, multi-layer
  – Future: ?

• In one word, it is a large-scale, complex, interconnected, non-linear system.
North America Interconnections
Current Midwest Electric Grid
Handle the Headachy System

- Monitoring: SCADA
- Classification of operating states
  - Normal
  - Restorative
  - Alert
  - In extremis
  - Emergency
- Specification of control objectives under different operating modes
Hierarchical Control Under Normal Condition

• All system variables are within the normal range and no equipment is being overloaded. The system operates in a secure manner and is able to withstand a contingency without violating any constraints.
• Assumption 1: P-f and Q-V are weakly decoupled.
• Assumption 2: any system change would primarily affect the system only locally and that the effects on the rest of the system are secondary.
Hierarchical Control Under Normal Condition

<table>
<thead>
<tr>
<th>Spatial</th>
<th>Primary</th>
<th>Secondary</th>
<th>Tertiary</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Equipment Based (Inertia, loads,</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>excitation systems, governors)</td>
<td></td>
<td>Regional Based</td>
</tr>
<tr>
<td>Temporal</td>
<td>Fast (2-10 sec)</td>
<td>Slower (5-60 min)</td>
<td>Slowest</td>
</tr>
</tbody>
</table>
Active Power and Frequency Control: Down-to-top Approach

- Equipment based:
  - Governor with steady-state feedback
- Utility based:
  - Unit commitment and economic dispatch
- Area based:
  - Automatic real power generation control (AGC)
- Regional based:
  - Adjust the setpoint frequency
Primary Control: Equipment Based

- Fundamental of speed governing

- Local primary control is the fastest automatic control for small frequency fluctuation
Utility Based Operation: Economic Dispatch and Unit Commitment

• Objective: minimize the expected operation cost while satisfying all the system constraints

• Mathematical formulation: an optimal control problem:

$$\min_{I^T_i, I^G_i, P_i} E\left\{ \sum_{i} \int_{0}^{T} (e^{-\rho t} (c_i (t, P_i (t))) + C_i^G (K_i^G (t), I_i^G (t), t)) dt + \sum_{i} \int_{0}^{T} C_i^T (K_i^T (t), I_i^T (t), t) dt \right\}$$

  – Subject to investment equations
  – Subject to technical limits (transmission and generation capacity)
  – Subject to spot price dynamics (F.C. Schweppe)
Area Based Control: AGC

• The primary objectives of *automatic generation control* (AGC) are to regulate frequency to the specified nominal value and to maintain the interchange power between control areas at the scheduled values by adjusting the output of selected generators. This function is commonly referred to as load-frequency control. A secondary objective is to distribute the required change in generation among units to minimize operating costs. (P. Kundur, Power System Stability and Control)
Area Based Control: AGC

• Assumption: in stationary operation, power system frequency is observable at each location and reflects the total system generation-demand imbalance.

• Measurement: area control error (ACE)

\[
ACE^I[k\tau_s] = F^I[k\tau_s] - 10B^I \frac{\omega[k\tau_s]}{2\pi}
\]

• System frequency depends on the sum of the subsystem biases.
Functional Diagram of a Typical AGC System

- Other control areas
- Control Area
- Other control areas
- Daily schedule for all generators
- Generation scheduling executed day before
- Economic dispatch
- Tie line flow
- Frequency deviation
- Raise/lower control signals
- Generation on AGC
- Generation not on AGC
- Decision making

Le Xie  lx@andrew.cmu.edu
Reactive and Voltage Control

- Utility-specific
- Less standardized and less automated

Methods for voltage control:
- Sources or sinks of reactive power
- Line reactance compensators
- Regulating transformers
EPSE for Emergency Operation

• Alert operating mode
  – Operation still under normal state

• Emergency operating mode: N-1 criteria
  – Stability crisis
  – Viability crisis
  – Integrity crisis
  – Restoration
Challenges to EPSE in Deregulation

• How to establish the right balance between system robustness to unexpected events
• How to set up appropriate markets corresponding to the system reliability requirements
• How to set up appropriate economic incentive so that the operation could be done under competitive markets
Open questions