Frequency responsive load

James Nutaro, John Kueck, Isabelle Snyder
Oak Ridge National Laboratory
nutarojj@ornl.gov
19/20 October 2010
Washington, DC
**Relevance to OE**

- Responsive loads can reduce energy costs and increase power system reliability by providing ancillary services – regulation, spinning reserve and operating reserve.

- Loads that react autonomously to frequency events are an important part of the mix of responsive loads
  - React immediately
  - Do not require a supporting communications network
  - Can be cost-effective

“PNNL 'smart' technology helps homeowners reduce grid stress”. Pacific Northwest National Laboratory Community & Regional Outreach, Vol. 4, No. 4, August 2009

The ORNL/UTK GridEye sensor, a high precision device for measuring frequency at 110V outlets.
Goal and Approach

- Goal is to understand the stabilizing effect that frequency responsive load has on electro-mechanical transients in a power system
  - Look specifically at sensitivity and intensity of load response

- Approach
  - Collaborate
    - Pacific Northwest National Laboratory
    - Montana Tech
    - University of Tennessee – Knoxville
  - New models
    - frequency sensors and actuators located at loads
  - Sensitivity studies based on IEEE 300 bus model
    - Eigenvalue analysis
    - Simulation
General properties

Swing equation
\[ \dot{\omega} = \frac{1}{M} (P_m - P_e) - D \omega \]

Generator output control
\[ \dot{P}_m = -k_m \omega \]

Frequency responsive load
\[ P_e = k_e \omega \]

Rapid, proportional response by the load always improves dynamic stability

Eigenvalues
\[ -\frac{1}{2} \left( D + \frac{k_e}{M} \right) \pm \frac{1}{2} \sqrt{\left( D + \frac{k_e}{M} \right)^2 - \frac{4k_m}{M}} \]

Imaginary axis

Real axis

Stable

Unstable
Extension to IEEE 300 bus system

- Standard model for studying electromechanical stability
  - Generators with speed and excitation controllers
  - Algebraic model of loads and transmission

- Augmented model of loads
  - Sensor detects change in frequency \textit{at the load}
  - Sensitive to change in increments $\Delta f$
  - Actuator changes load in proportion to change
  - Proportionality constant for change is $k_e$
Sensor modeling: the problem

- Frequency at loads is *not* a dynamic variable in the model
- Numerical derivative of the phase angle is not suitable
  - Spurious, non-physical spikes in frequency
  - Frequency at bus exceeds frequencies at generators
  - Induces inappropriate and unrealistic response in the loads

Comparison of methods for calculating frequency at a load bus. From draft report “Simulation of Dynamic Frequency Measurements by Frequency Disturbance Recorders (FDRs)“, Ghadir Radman, Tennessee Tech University
Sensor modeling: a solution

- **Model of the generator** affects phase angle at the *model of the load* by
  - Excitation control
  - Speed control
- Follows directly from the model’s mathematics that
  - Excitation control causes ‘spurious’ changes in frequency at loads
  - Speed control produces expected changes in frequency
- **Result**
  - New method for calculating frequency at load
  - *Method built into the ORNL power system simulator*
Frequency without responsive load

- Average frequency response to step change in load (0.13% change in total demand)
Frequency with responsive load, part 1

- Maximum frequency excursion shrinks as $K_e$ grows
- Trend agrees with eigenvalue analysis

$K_e \approx 1/R_l$
**Frequency with responsive load, part 2**

- Same general trend as before
- Finer sensitivity to frequency improves response

\[ K_e = 1000 \quad \Delta f = 0.001 \]

\[ K_e = 100 \]

\[ K_e = 10 \]

\[ K_e \sim 1/R_l \]
Summary of technical results

- Frequency responsive load improves dynamic stability
  - Proportional control works
  - Higher resolution in frequency measurements gives better results
  - Eigenvalue analysis suggests that more is better
  - Simulations reinforce this conclusion

- New models of sensors are needed for these types of simulation studies
  - Sensors at the loads are a major component of the system
  - ORNL addressed this problem by developing and implementing a new technique for sensor modeling

The ORNL/UTK GridEye sensor, a high precision device for measuring frequency at 110V outlets.
In progress: comparison with EMTP

- Aiming at same studies on EMTP based on IEEE300 bus model
- Will the models agree?
- Modeling nearly done, test cases look promising

<table>
<thead>
<tr>
<th>System 1</th>
<th>System 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generation Load</td>
<td>7585 MVA</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>System 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Generation Load</td>
</tr>
</tbody>
</table>

Load addition of 2000MW; 250 MW at each interconnection line
Early test with EMTP

Control based on frequency deviation Δf
1- Normal conditions
2- No governors Δf < -0.002Hz/1us (OFF) and f > 60Hz (ON)
3- No governors Δf < -0.002Hz/100us (OFF) and f > 60Hz (ON)
Summary of outcome; future work

- **Outcome: proportional control of load improves dynamic stability**
  - We will compare results with PNNL and Montana Tech and EMTP outcomes when their results are available

- **Outreach:**
  - Forthcoming report details results of this study
  - New method for modeling sensors will facilitate an improved understanding of distributed, autonomous control in the smart grid

- **Future work:**
  - Validation of the sensor model
    - GridEye data collected at ORNL and UTK will enable this
  - Systems engineering studies in collaboration with utilities
    - How can small, distributed devices realize a collective, proportional response
    - What is the impact on a real systems
  - Simulator development in collaboration with tool venders
    - Integrate sensor models with commercial tools