THE EFFECTS OF VERY FAST RESPONSE TO FREQUENCY FLUCTUATIONS

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Outline

• Introduction
• Frequency Control
• System Modeling
• Simulation Results
• Discussion
• Future Work
• References
Introduction

- Frequency control
  - an essential task of the power system operator
  - becoming more important as the penetration of intermittent resources, such as wind, increases
  - traditionally, achieved by changing the power output of dispatchable resources which usually have restricted ramp rates
  - currently, can be provided by fast-ramping resources, such as storage

- Fast-ramping resources
  - may provide more accurate responses to frequency fluctuations.
  - can be more effective than thermal generators in providing frequency regulation service.
  - reduce the regulation capacity that the operator needs to procure
Introduction

- Current compensation method for regulation
  - solely based on the capacity reserved for regulation
  - does not take into account the advantages of fast-ramping resources
- FERC Order 755
  - has mandated all market operators to update their compensation methods by considering the accuracy in response to the AGC signal
    → pay for: capacity + performance

Questions:
- What is the real value of fast-ramping resources?
- Is there any adverse effect of fast responses to frequency fluctuations?

Existence of adverse effects
- may change the decision on additional payment for the performance of fast-ramping resources
- should be investigated
Frequency Control

- There are different levels of frequency control in a power system:
  
  - **Inertial frequency response** (natural response)
    
    Any sudden change in load or generation is initially compensated by addition or extraction of kinetic energy from the rotating inertia of all synchronous generators and motors.
  
  - **Primary Frequency Control** (Governor Response)
    
    An external control loop of a turbine which regulates the rotation speed of the shaft by changing the supply to the turbine and thus control frequency.
  
  - **Secondary Frequency Control** (LFC / AGC / Regulation / …)
    
    A centralized automatic control which is designed to restore the frequency to its set point.
System Modeling

- An appropriate dynamic model of the system is needed for studying the effects of using fast-ramping resources.

Figure 2: The schematic block diagram of frequency response model (based on [12])
System Modeling

• System Inertia Model
  • Based on the dynamic relationship between the mismatch power and the frequency deviation,

\[ \Delta P_G(t) - \Delta P_L(t) = 2H \frac{d\Delta f(t)}{dt} + D \Delta f(t) \]

the transfer function of the system inertia model can be expressed as:

\[ \frac{1}{D + 2Hs} \]

H is the inertia constant and D is the load damping coefficient which is usually expressed as a percent change in load for a 1% change in frequency.
System Modeling

• Generator Model
  • a number of low order models for representation of generator dynamics have been proposed. These models usually ignore the slow system dynamics of the boiler and the fast generator dynamics.

Figure 3: The Block diagram of generator (based on [12])

Table 1: The transfer functions of generator model (based on [12])

<table>
<thead>
<tr>
<th>Unit</th>
<th>Governor Transfer Function</th>
<th>Turbine Transfer Function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Non-reheat Steam Unit</td>
<td>$\frac{1}{1+T_g s}$</td>
<td>$\frac{1+T_{fr}s}{1+T_t s}$</td>
</tr>
<tr>
<td>Reheat Steam Unit</td>
<td>$\frac{1}{1+T_g s}$</td>
<td>$\frac{1+T_{fr}s}{(1+T_t s)(1+T_f s)}$</td>
</tr>
<tr>
<td>Hydraulic Unit</td>
<td>$\frac{1}{1+T_g s} \frac{1+T_{gh}s}{1+0.5T_{ch}s}$</td>
<td>$\frac{1+T_{gh}s}{1+0.5T_{ch}s}$</td>
</tr>
</tbody>
</table>
System Modeling

- **LFC Model**
  - Maintaining frequency and controlling the net power interchanges with neighboring control areas at the scheduled values are main objectives of LFC.
  - For meeting these objectives, a control error signal, called the area control error (ACE), is measured. ACE is a linear combination of net interchange and frequency deviations.

\[ ACE_i = \Delta P_{tie,i} + \beta_i \Delta f_i \]

where \( \beta \) is a bias factor of each area

- After measuring and filtering the ACE, it is used as an input for a controller which is usually a proportional integral (PI) controller. Then based on the resulted control signal and the participation factors of all the LFC participant units, the new set points are calculated and sent to the generators.
Simulation Results

- The effects of using fast-ramping resources for providing regulation is studied for two different examples.
- For assessing the performance of the system in frequency control, NERC Control Performance Standard 1(CPS1) is used.
- CPS1 can be calculated based on a compliance factor (CF1):

\[
CF1 = \frac{1}{\varepsilon^2} \left( \frac{ACE}{-10\beta} \right)_1 \{\Delta f\}_1
\]

\[
CPS1 = 100(2 - \{CF1\}_t)\%
\]

\(\varepsilon\) is a constant defined by NERC for each interconnection.
- Based on the definition of ACE, for an isolated system CF1 can be simplified to:

\[
CF1 = \frac{(\{\Delta f\}_{1_{\text{min}}})^2}{\varepsilon^2}
\]
- For each area, a CPS1 score over a rolling 12 months should be at least 100% to meet the compliance requirement of NERC. The maximum score is 200%.
Simulation Results

• Example 1:
  • The system is supposed to have the unlimited capacity of ideal fast-ramping resources which can respond to AGC signal instantaneously.
  • The LFC system will share the amount of deployed regulation between fast-ramping resources and the traditional generators based on a fixed ratio named α.

• System parameters:

<table>
<thead>
<tr>
<th>LFC System</th>
<th>Governor Model</th>
<th>Governor Speed Droop</th>
<th>Turbine Model</th>
<th>System Inertia</th>
</tr>
</thead>
<tbody>
<tr>
<td>$k(s)$</td>
<td>$\frac{1}{1 + T_g s}$</td>
<td>$R$</td>
<td>$\frac{1}{1 + T_c s}$</td>
<td>$\frac{1}{D + 2H s}$</td>
</tr>
<tr>
<td>$-0.3/s$</td>
<td>$T_g = 0.08$</td>
<td>$R(\text{Hz/pu}) = 3$</td>
<td>$T_c = 0.40$</td>
<td>$D (\text{pu/Hz}) = 0.015$</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$2H (\text{pu/s}) = 0.1667$</td>
</tr>
</tbody>
</table>
Simulation Results

- Example 1:
  - System response to a step load disturbance
Simulation Results

- Example 1:
  - System response to a sequence of load disturbances
Simulation Results

- Example 1:
  - CF1 values for each minute of system response to a sequence of load disturbances
Simulation Results

- Example 2: ERCOT System
  - Model parameters is calculate by using the minimum square based identification method and data from a contingency in January 2010.
  - The controller in the LFC model of ERCOT is a “proportional” controller with gain that varies with ACE.

| Condition               | \(||ACE|| \leq 62| | |\) | \(|62 < |ACE|| \leq 90| | |\) | \(|90 < |ACE|| \leq 334| | |\) | \(|334 < |ACE||\) |
|-------------------------|------------|------------|------------|------------|
| LFC Controller Gain     | 0          | 0.3        | 0.4        | 0.8        |

Table 3: LFC controller gain in ERCOT
Simulation Results

- Example 2: ERCOT System
- System response to a sequence of load disturbances
Simulation Results

- Example 2: ERCOT System
  - CF1 values for each minute of system response to a sequence of load disturbances
Discussion

- Previous studies have shown that fast-ramping resources can result in more accurate response to AGC signal, less regulation capacity procurement and more economic efficiency.
- However, the results of our study show that using fast-ramping resources for providing regulation can change the dynamic behavior of the system.
- As these changes could result in reduced CPS1, these resources are not always desirable.
- Hence, fast-ramping resources have the potential to worsen the frequency control performance of power system.
Future Work

- For more reliable results, the simulation should be done for a longer periods of time. To achieve this goal, more operational data is needed for constructing the system model in different situations.

- A detailed model of thermal generators is needed which could specifically show the related delays, ramp rate limits and deadbands.

- Future work may consider the constraints of fast-ramping resources (like limited capacity).

- New reasonable indices may enable us to better compare the dynamic frequency response of the system. Defining new reasonable indices and should be investigated.

- System operator may need to change the LFC method to calculate an appropriate AGC signal for fast-ramping resources to avoid their adverse effect.
References


6. Christopher L. DeMarco, Chaitanya A. Baone, Yehui Han, and Bernie Lesieutre, “Primary and Secondary Control for High Penetration Renewables,” PSERC Publication, March 2012.


Thank you.