Diverse Fast Frequency Response Services in Systems with Declining Synchronous Inertia

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Why Fast Frequency Response (FFR)?

• Buys time for Primary Frequency Response (PFR), to act.

• In this construct, the sole benefit of FFR is to improve the frequency Nadir -- and avoid under-frequency load-shedding (UFLS)

• The economic benefit of not depending solely on PFR can be significant, especially as RoCoF increases and inertia decreases.
Inertia, PFR and FFR

Historical Perspective

- Traditional systems relied on “spin” (or some variation on the theme), of which a portion was fast enough to provide sufficient arresting power to avoid UFLS

Source: NERC FRIR

Primary Frequency Control
[Governor response (and frequency-responsive demand response)]

Secondary Frequency Control
(Generators on Automatic Generation Control)

Tertiary Frequency Control
(Generators through operator dispatch)

Source: NERC FRIR
Inertia, PFR and FFR

Historical Perspective (continued)

• As inertias have dropped, RoCoF has become steeper/greater

• Need for speed has increased

• Creates an opportunity to reward provision arresting power by a new product: FFR is born

• Success is now a function of 3 parameters: Inertia, PFR and FFR

• ERCOT has lead the industry in describing and quantifying relationship between the three

Source: NERC FRIR
Why “generalized” FFR?

• Natural assumption is that “faster is better”
• Not all technologies have the same performance characteristic.
• In order to maximize the technologies that can participate, it is necessary to:
  • Provide a construct by which dissimilar behaviors can be fairly compared
  • Provide construct by which an adequate supply of heterogeneous resources can be determined
“generalized” FFR

- Concept is to develop an “efficacy mapping” that is system specific

- Concept illustrated here with an example system
  WECC System
  Design basis event (trip Palo Verde NPS)
  Each 500ms inject “ideal” block of arresting energy:
  
  1000MW for ½ second = 500MJ

- Record impact on Frequency Nadir
"generic" FFR: Calibration Simulations

One data point

- Inject "ideal" 1000MW FFR for ½ second: 500MJ of arresting energy, starting (for this case) at 3.0 seconds after the event is initiated.

- Injection improves Nadir frequency by this much.

- Injection delays the time of the Nadir frequency by this much.
“generic” FFR: Calibration Simulations

An entire sequence of FFR perturbation runs
Black trace is reference case
Calibration

• Each case results in a measurable impact on the nadir.
• Up to the time of the nadir...obviously actions after the nadir don’t help (in this regard)
• Faster isn’t better!
• But too slow, is even worse
Each unit of arresting energy has value

![Graph](image-url)

**FFR Efficacy vs. Timing**

- **Efficacy** (μHz/MJ)
  - 12.0
  - 10.0
  - 8.0
  - 6.0
  - 4.0
  - 2.0
  - 0.0
  - -2.0

- **Time of FFR Injection**
  - 0
  - 1
  - 2
  - 3
  - 4
  - 5
  - 6
Bucketize

FFR Efficacy vs. Timing

![Graph showing FFR Efficacy vs. Timing with bars indicating efficiency at different times of FFR injection.]

-1 0 0.5 1 1.5 2 2.5 3 3.5 4 4.5 5 5.5

Efficacy (μHz/MJ)

Time of FFR Injection
Evaluate a Signature

Try with “Real” complex FFR energy injection

A complex FFR signature
Bucketize Signature

Line up with Efficacy curve

FFR Arresting Energy

Arresting Energy (MJ)

Time of FFR Injection (sec)
Calculate Expected Impact

**FFR Efficacy vs. Timing**

- Efficacy (kHz/MJ)
- Time of FFR Injection

**Component Expected FFR Impact on Nadir**

- Nadir Improvement (kHz)
- Time of FFR Injection (sec)

**FFR Arresting Energy**

- Arresting Energy (MJ)
- Time of FFR Injection (sec)
Estimate Cumulative Impact on Nadir

Expected improvement in Nadir is 1.35mHz
For small perturbations, the technique appears to give perfect results

A complex FFR signature and resultant frequency excursion

Nadir improves 1.35mHz
Compare across operating conditions

Summer Heavy Load

- Efficacy is much higher for “lighter” system: not surprising
  - \( H_{\text{summer}} = 860 \text{ GW-sec} \)
  - \( H_{\text{spring}} = 394 \text{ GW-sec} \)

- It is less obvious that the timing of the heavy summer curve should be to the left (faster) than the lighter load curve.
  - Could just be that the event is less bad.
How might this be used?

• Efficacy of *any* FFR resource can be evaluated based on the desired outcome.

• In planning, less need to evaluate a wide range of FFR characteristics;

• For FFR resources that can be tuned, selecting preferred settings becomes relatively simple

• Allows for easier evaluation of FFR vs PFR, for planning and for procurement
Conclusions (so far)

• Approach Works well for small perturbations
• Optimum speed of FFR is dependent on the system and the operating condition
• Signal of a specific system changes in magnitude, but not much with operating condition (e.g. light vs heavy load).

Probably not true for huge changes or major topology changes
Work to be done

- Large Signal work
  - How Linear is the process?
  - How much would the signature change
- Can this be further simplified
- Is this a viable approach for procurement?
- Need better understanding of relationship to the amount and speed of PFR
Acknowledgements

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Using Smart Loads to Provide Primary Frequency Response at Hydro-Québec

Presented to the Essential Reliability Services Working Group
11/09/2016 SCEG, SC

Francis Monette, Hydro-Québec TransÉnergie
Presentation summary

• Context
• Choosing the right load to operate
• Smart load features and requirements
• Frequency measurement
• Smart load services
• Control strategies
  – Primary Frequency Response
  – Contingency Reserve
• What’s next?
Hydro-Québec Research institute and Systemex Energies established a partnership to study and develop the smart loads concepts.

Hydro-Quebec uses the existing technology developed by Systemex as a research platform.

The idea is to modulate load in reaction to frequency in order to maintain balance between load and demand, thus frequency.

A study was performed by Hydro-Québec TransÉnergie to evaluate potential frequency behavior using smart loads.
• This figure shows simulation results for a loss of generation of 1 200 MW during mean summertime power system conditions and was simulated with PSS/E using a detailed model of Hydro-Québec’s power system.
Choosing the right load to operate

• The technology can be used with many type of loads
• It was decided to use the domestic electric water heater as the load to modulate because:
  – The water contained in the electric water heater tanks acts as a very cost effective form of energy storage.
  – There is merely no impact for end users and most of the water heating in Quebec is done with electric water heaters (91%).
  – Water heaters are used year round which is, for instance, not true for electrical heating systems.
Smart loads Features and requirements

• Need an accurate measure of frequency.
• Offer a fast reaction to provide frequency response <250 ms.
• Offer a proportional response instead of on/off operation.
• Are adaptable and configurable in order to implement various services
• Need to be autonomous.
• Should not alter power quality for customers.
Frequency measurement

• The measurement is realized every half cycle with an accuracy of approximately 2-5 mHz (to be validated in lab).
• The algorithm filters local events and faults on the BES to prevent inadequate operation.
• The measure is consistent among the 5 units installed on the grid.
Smart Loads services

• In the project, various services were implemented in the loads:

<table>
<thead>
<tr>
<th>Service</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary Frequency Response</td>
<td>Automatic</td>
</tr>
<tr>
<td>Continous primary regulation</td>
<td>Automatic</td>
</tr>
<tr>
<td>Cold load management</td>
<td>Automatic</td>
</tr>
<tr>
<td>Contingency reserve</td>
<td>Automatic / On demand</td>
</tr>
<tr>
<td>Demand side management</td>
<td>On demand</td>
</tr>
</tbody>
</table>

• The combination of services is important to ensure a good coordination and to get the most out of the resource.
The control strategy for water heaters can be divided in three distinct phases following a frequency excursion event:

- The initial load modulation upon a frequency variation.
- An aggregate load modulation management period of 15 minutes.
- A progressive load return to normal operation.

The initial load modulation follows the following criteria:

- Droop of 1%
- Modulation start of 59.8 Hz (deadband with load starting at 100% modulation)
- End of load modulation at 59.2 Hz
- Load modulation is linear between 59.8 and 59.2 Hz
Control strategy (Primary Frequency Response)

• The aforementioned control strategy was implemented, tested and performed as planned.
• As shown in this figure, five units installed on remote locations on the power system reacted the same way and at the same moment upon a frequency excursion.
• This figure also demonstrates the modulation of two consecutive events.
Control strategy (Contingency reserve)

• Once activated, the load modulation acts as follow:
  – The load gradually modulates linearly from 100% to 0% in 5 minutes.
  – The interruption is maintained for 90 minutes by default.
  – A progressive load return to normal operation using a linear ramp on two hours.
• All of these settings can be adjusted as required.
Conclusion and What’s next?

• The demonstration project showed that the technology works and that smart loads can provide various services.

• There are actually 5 units in operation since 21 months that responds to events and also provide measurements through wi-fi of Frequency, Voltage, % of modulation, Thyristor state, water temperature, etc...

• We aim to do a pilot project in 2017 in order to
  – Continue to test the devices
  – Measure aggregate load response and develop models
  – Confirm water heater models
  – Continue to develop the algorithms
Questions?

Thank you!